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**Sengoku**

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(54) **MULTI-LANE N-FACTORIAL (N!) AND OTHER MULTI-WIRE COMMUNICATION SYSTEMS**

(56) **References Cited**

U.S. PATENT DOCUMENTS

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4,644,547 A	2/1987	Vercellotti et al.
5,703,914 A *	12/1997	Nakamura .....
6,526,112 B1	2/2003	Lai
6,728,908 B1	4/2004	Fukuhara et al.
7,061,939 B1	6/2006	Chengson et al.
7,395,347 B2	7/2008	Nemawarkar et al.
7,502,953 B2	3/2009	Boecker et al.

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(Continued)

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FOREIGN PATENT DOCUMENTS

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JP	2008242884 A	10/2008
WO	WO-2007009038 A2	1/2007
WO	WO-2009111175 A1	9/2009

OTHER PUBLICATIONS

(21) Appl. No.: **14/250,119**

Williams A., "Synopsys describes MIPI DigRF protocol for 4G mobile," Retrieved from the Internet <URL: <http://www.electronicweekly.com/news/design/eda-and-ip/synopsys-describes-mipi-digrf-protocol-for-4g-mobile-2012-03/>>, 2012, 6 Pages.

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**H04B 1/38** (2015.01)  
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**H04L 7/033** (2006.01)  
**H04L 25/02** (2006.01)

(57) **ABSTRACT**

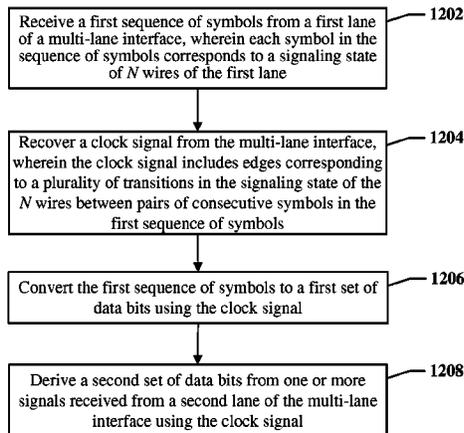
System, methods and apparatus are described that facilitate transmission of data over a multi-wire data communications link, particularly between two devices within an electronic apparatus. A clock extracted from a first sequence of symbols transmitted on a first lane of a multi-lane interface is used to receive and decode the first sequence of symbols and to receive and decode data and/or symbols transmitted on a second lane of the multi-lane interface. The clock signal may be derived from transitions in the signaling state of N wires between consecutive pairs of symbols in the first sequence of symbols. The first lane may be encoded using N! encoding and the second lane may be a serial or N! link.

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USPC ..... 375/220, 355  
See application file for complete search history.

**28 Claims, 15 Drawing Sheets**

1200 ↙



(56)

**References Cited**

U.S. PATENT DOCUMENTS

8,159,376	B2	4/2012	Abbasfar	
8,184,760	B2	5/2012	Chien et al.	
8,621,128	B2	12/2013	Radulescu et al.	
2004/0203559	A1*	10/2004	Stojanovic et al.	455/403
2010/0215118	A1	8/2010	Ware et al.	
2013/0225067	A1	8/2013	Card et al.	
2013/0241759	A1	9/2013	Wiley et al.	
2014/0254732	A1	9/2014	Sengoku et al.	
2014/0270026	A1	9/2014	Sengoku et al.	
2015/0098538	A1*	4/2015	Wiley et al.	375/355
2015/0220472	A1	8/2015	Sengoku	

OTHER PUBLICATIONS

Zhu C., et al., "Multi-Machine Communication Based on I2C-Bus," Sensors & Transducers, Jul. 2014, vol. 174 (7), pp. 138-143.

Partial International Search Report—PCT/US2015/041622—ISA/EPO—Apr. 21, 2015.

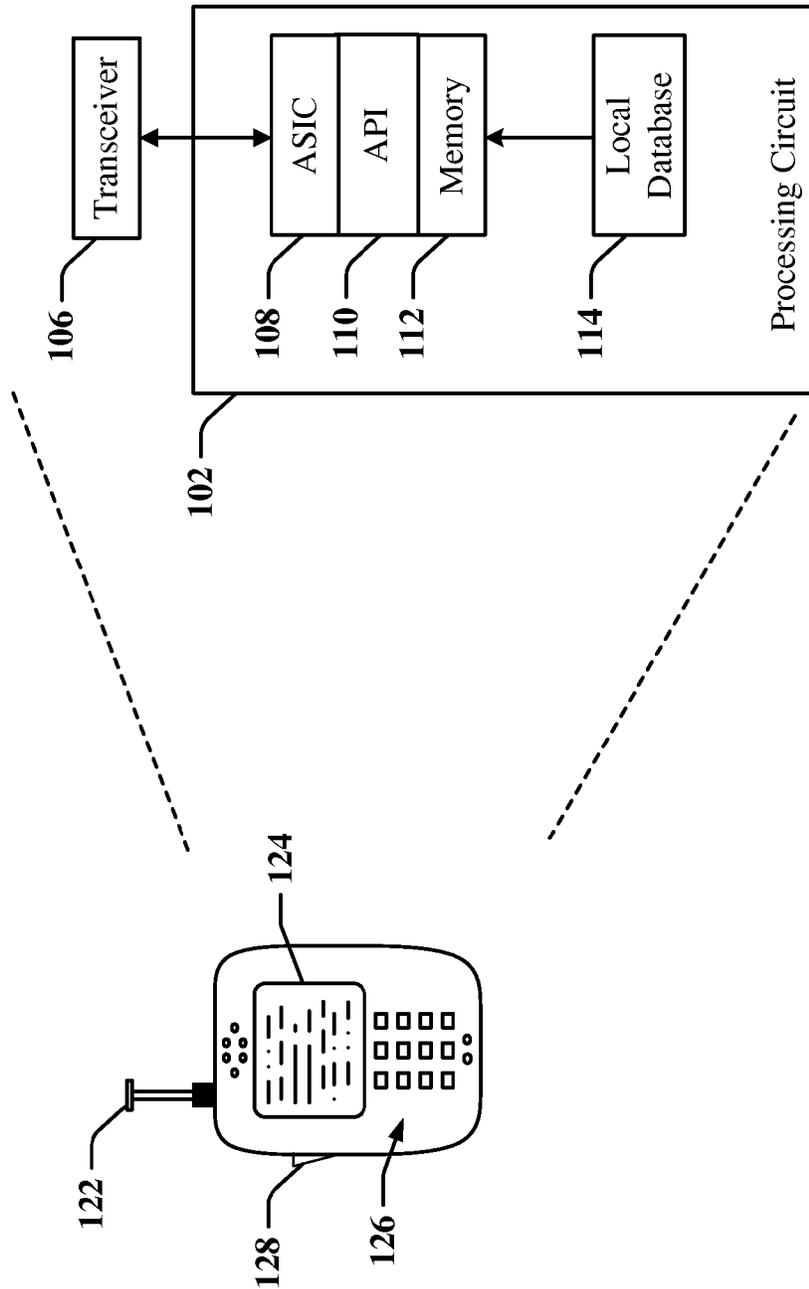
"Draft MIPI Alliance Specification for Camera Serial Interface 2 (CSI-2)" In:"Draft MIPI Alliance Specification for Camera Serial Interface 2 (CSI-2)", Apr. 2, 2009, XP055165978, 6. Camera Control Interface (CCI) 529-728.

Poulton JW., et al., "Multiwire Differential Signaling", Aug. 6, 2003 No. 1.1 Aug. 6, 2003, pp. 1-20, XP002610849, Retrieved from the Internet: URL:<http://www.cs.unc.edu/~jpfm/wire.pdf> [retrieved on Nov. 23, 2010] the whole document.

Zogopoulos S., et al., "High-Speed Single-Ended Parallel Link Based on Three-Level Differential Encoding", IEEE Journal of Solid-State Circuits, IEEE Service Center, Piscataway, NJ, USA, vol. 44, No. 2, Feb. 1, 2009, pp. 549-557, XP011243176, ISSN: 0018-9200, DOI: 10.1109/JSSC.2008.2011038 the whole document.

\* cited by examiner

100 ↗



**FIG. 1**

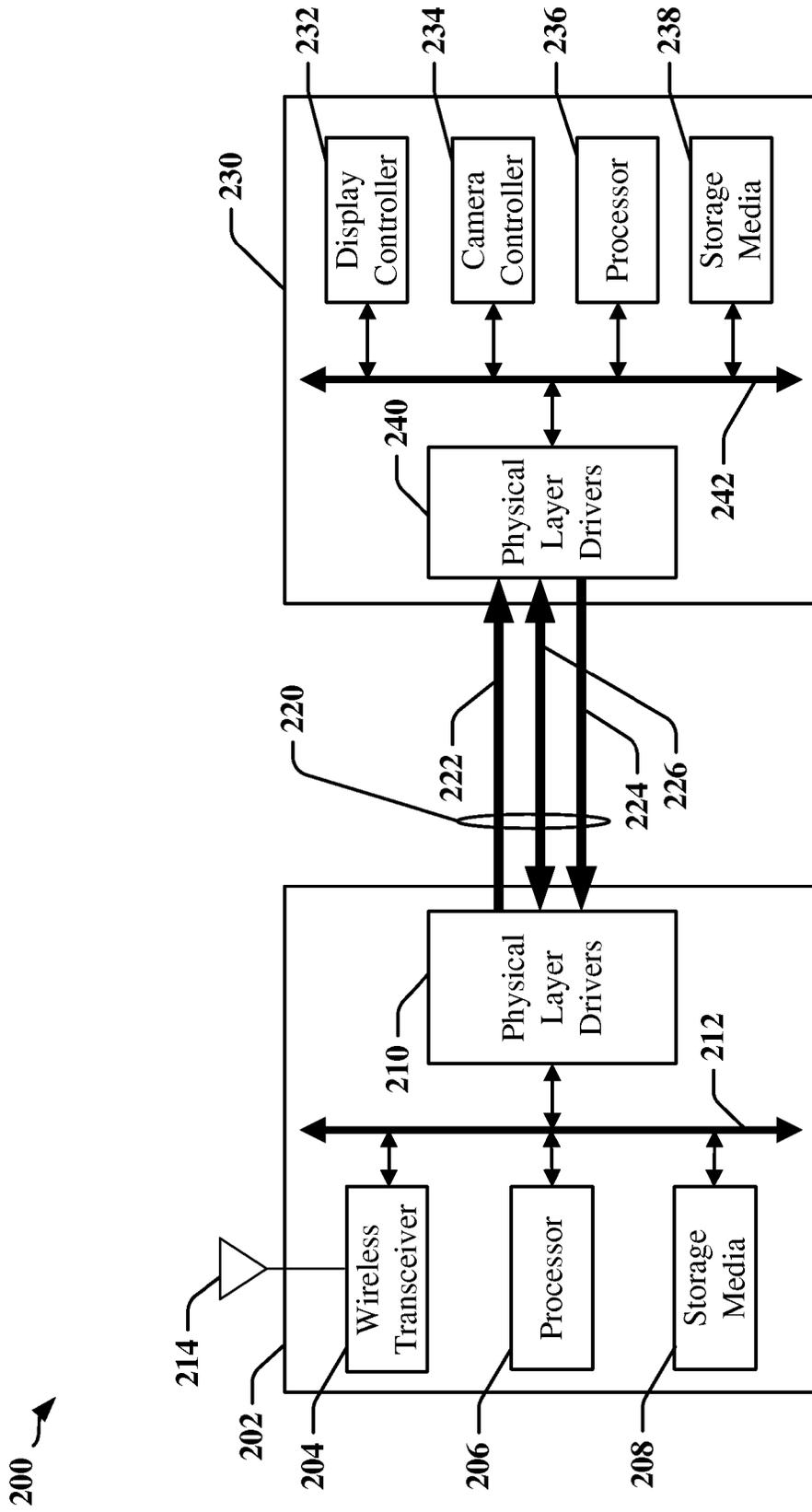


FIG. 2

300 →

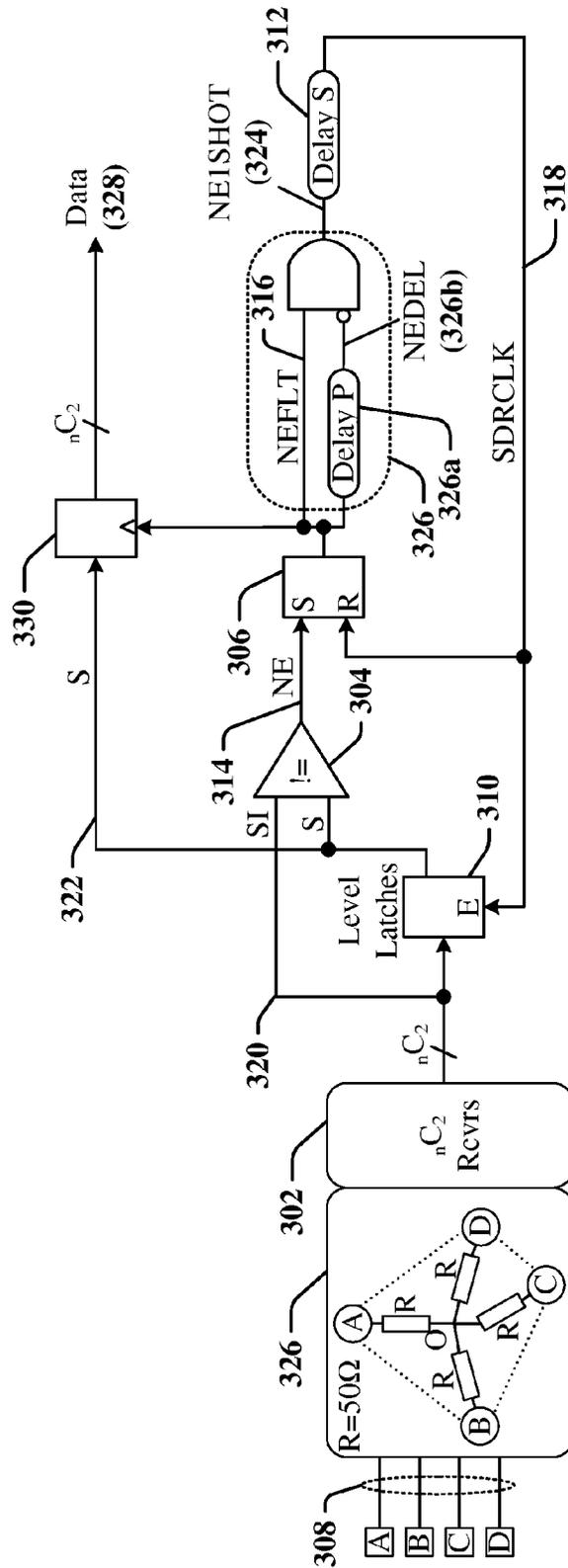


FIG. 3

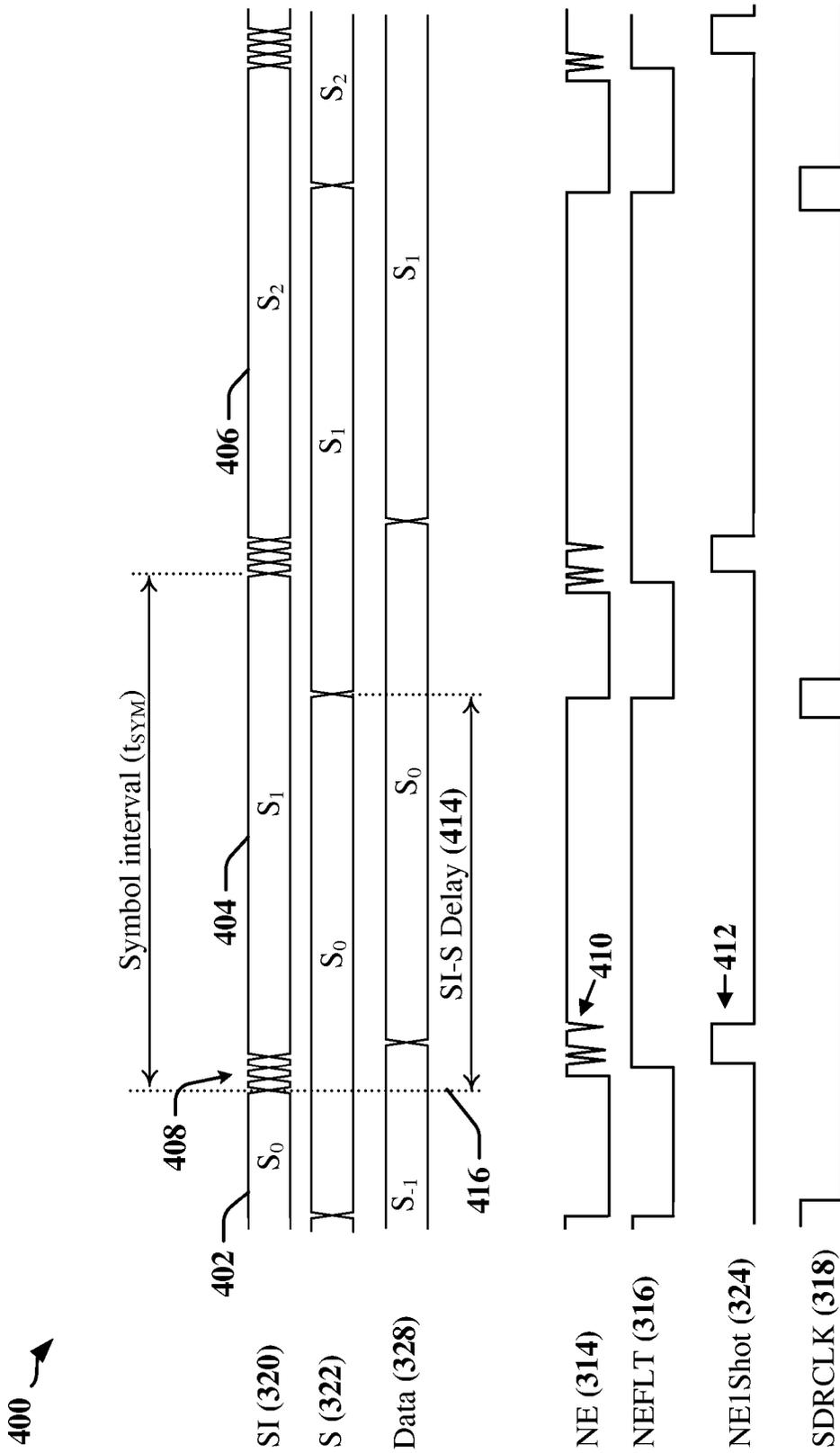


FIG. 4

500 ↗

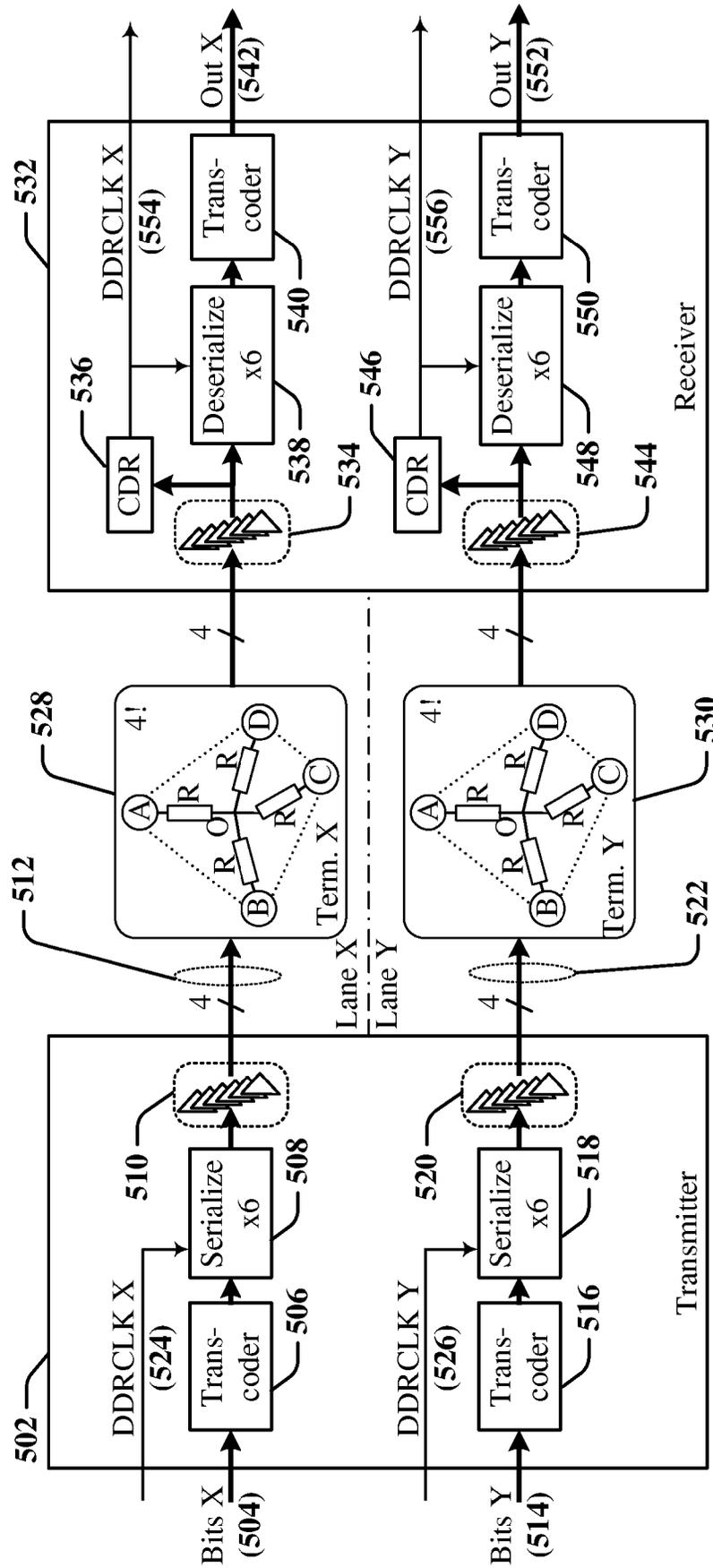


FIG. 5

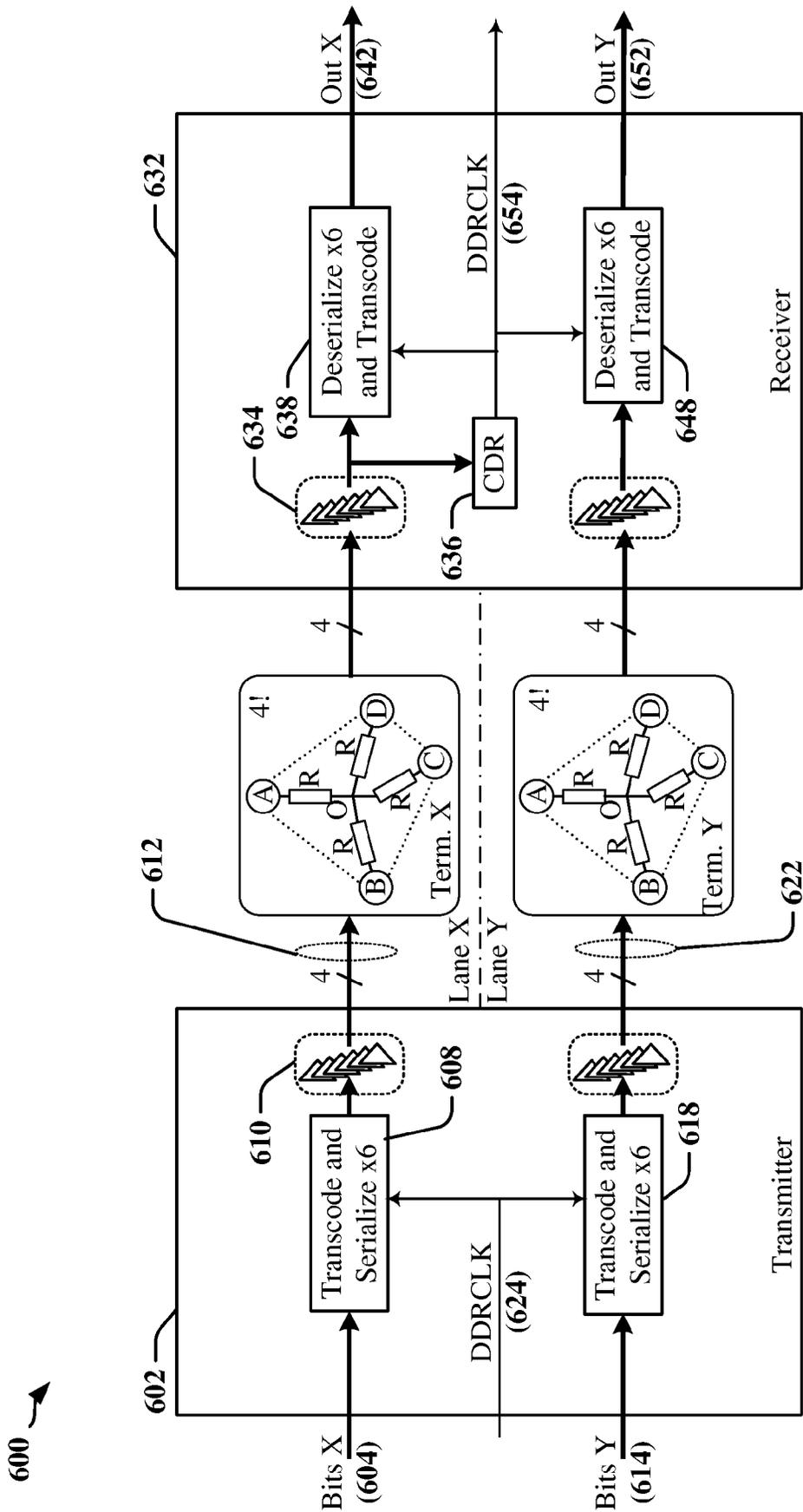


FIG. 6

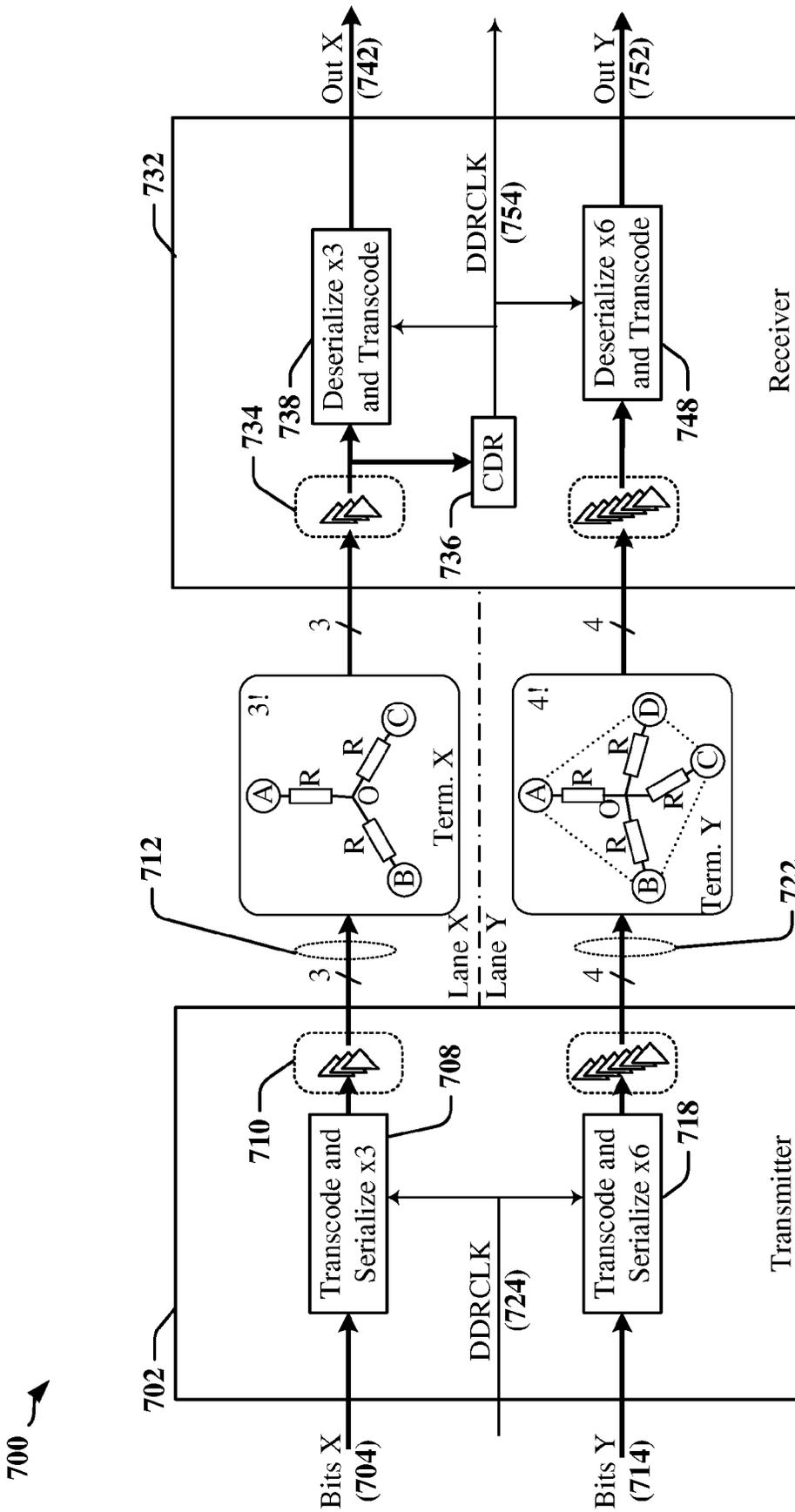


FIG. 7

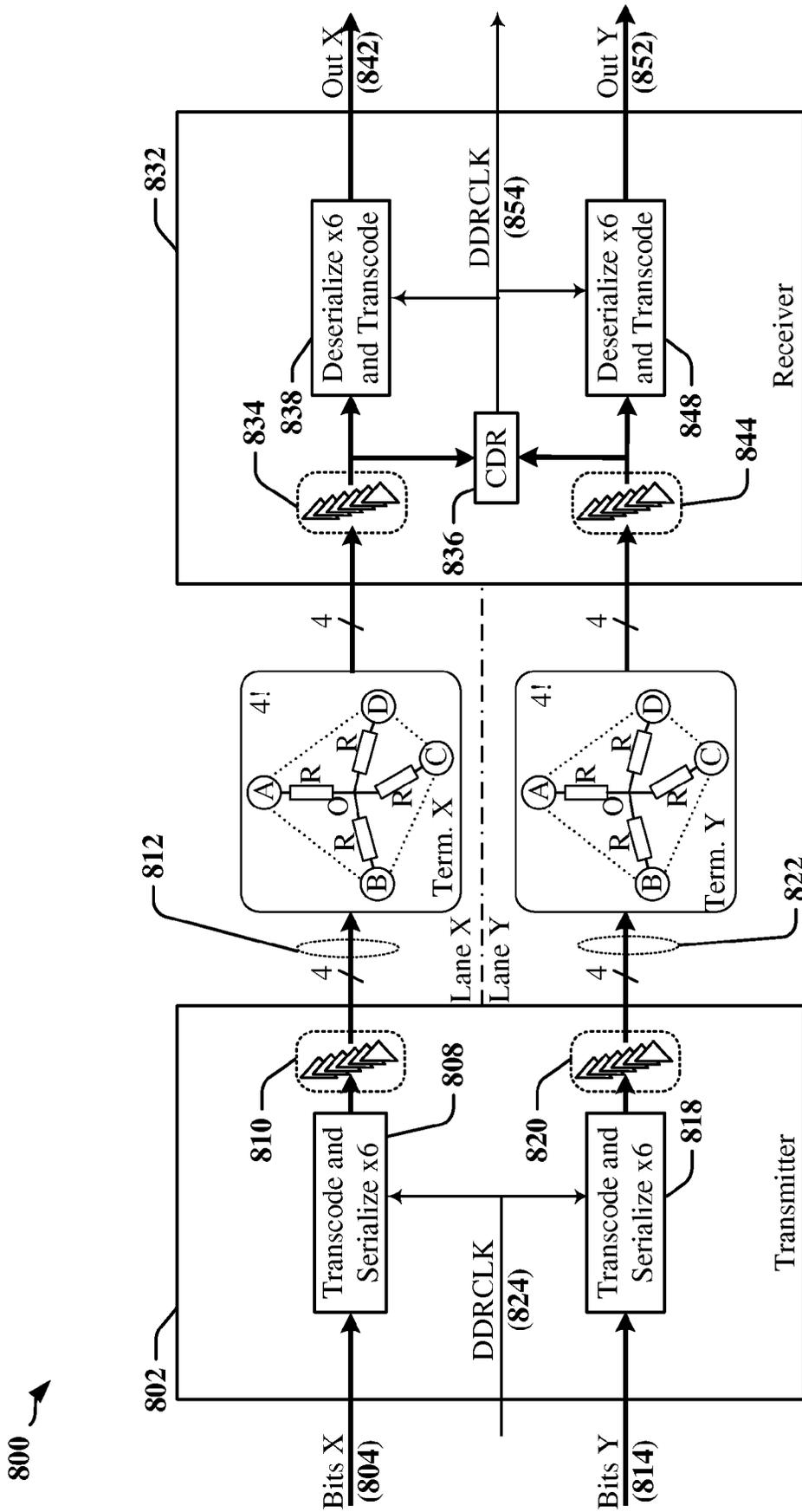


FIG. 8

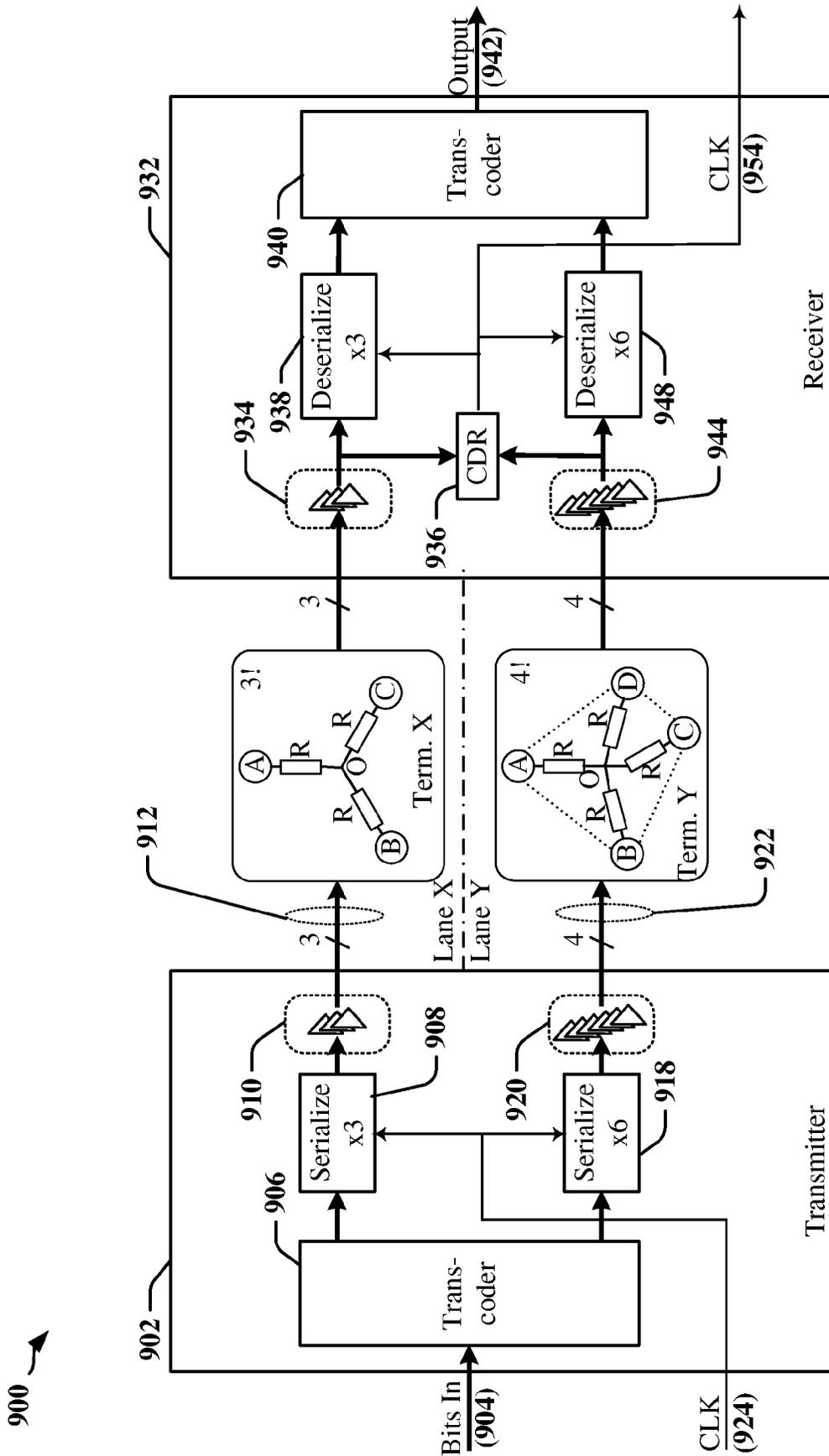


FIG. 9

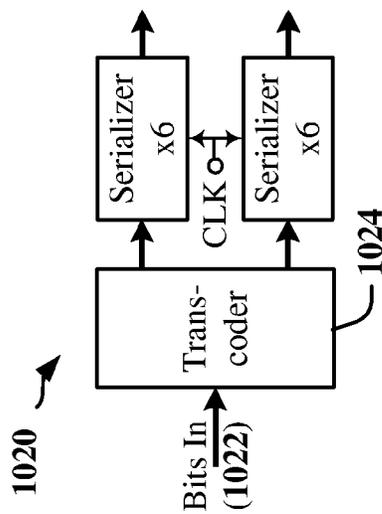
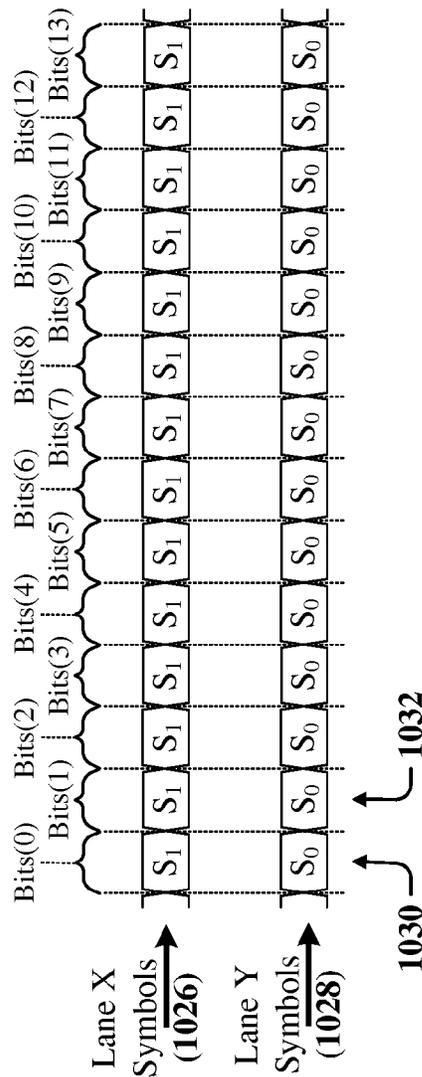
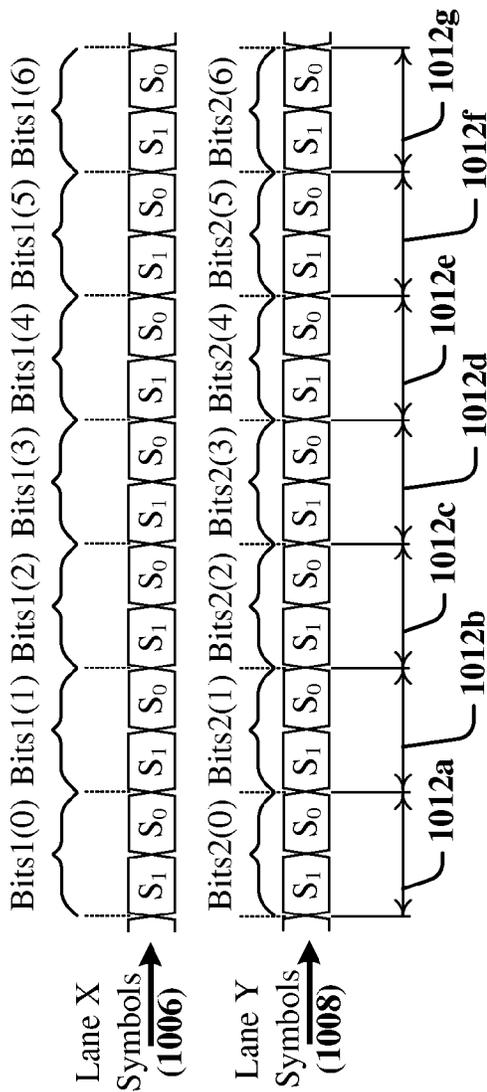
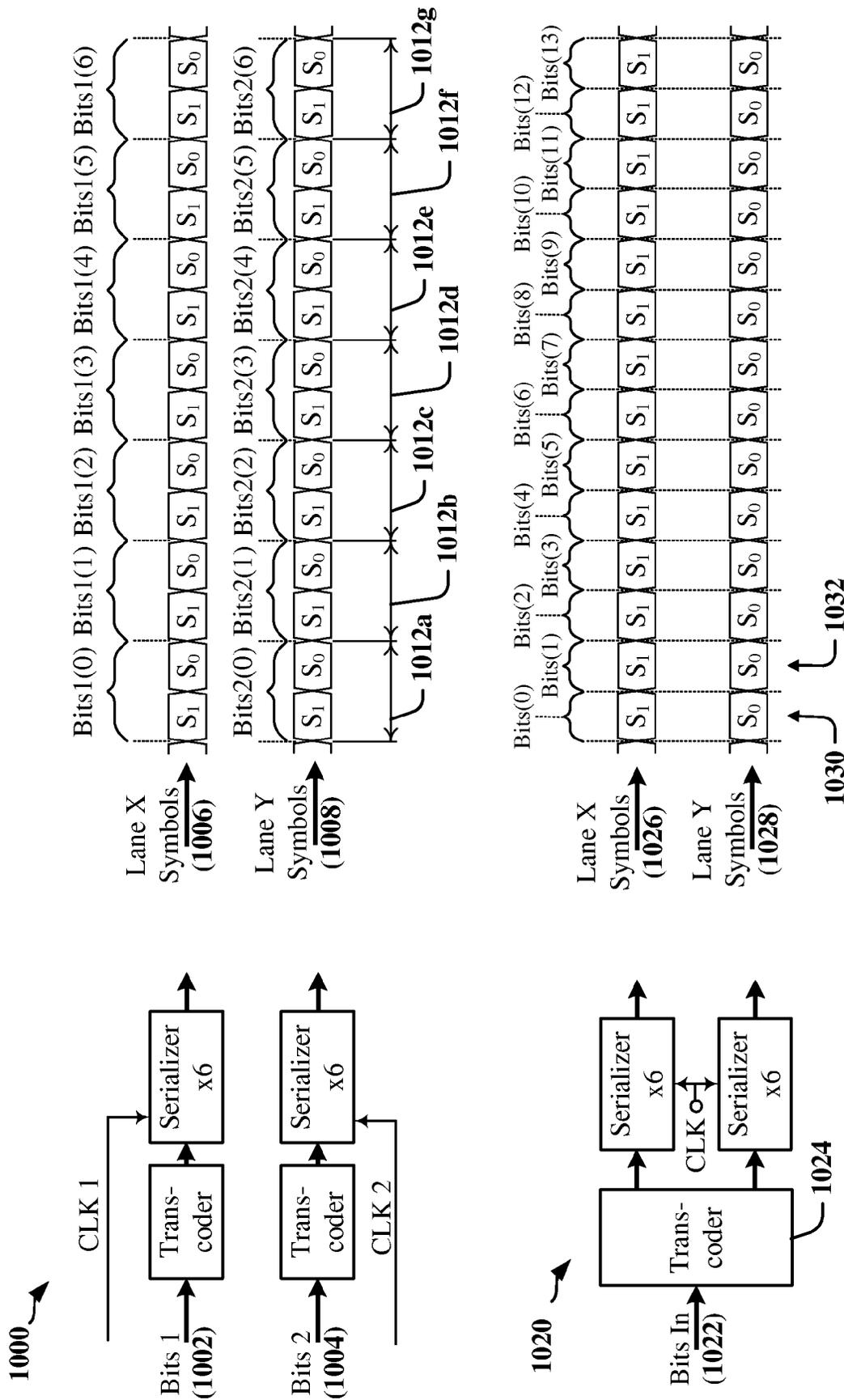


FIG. 10

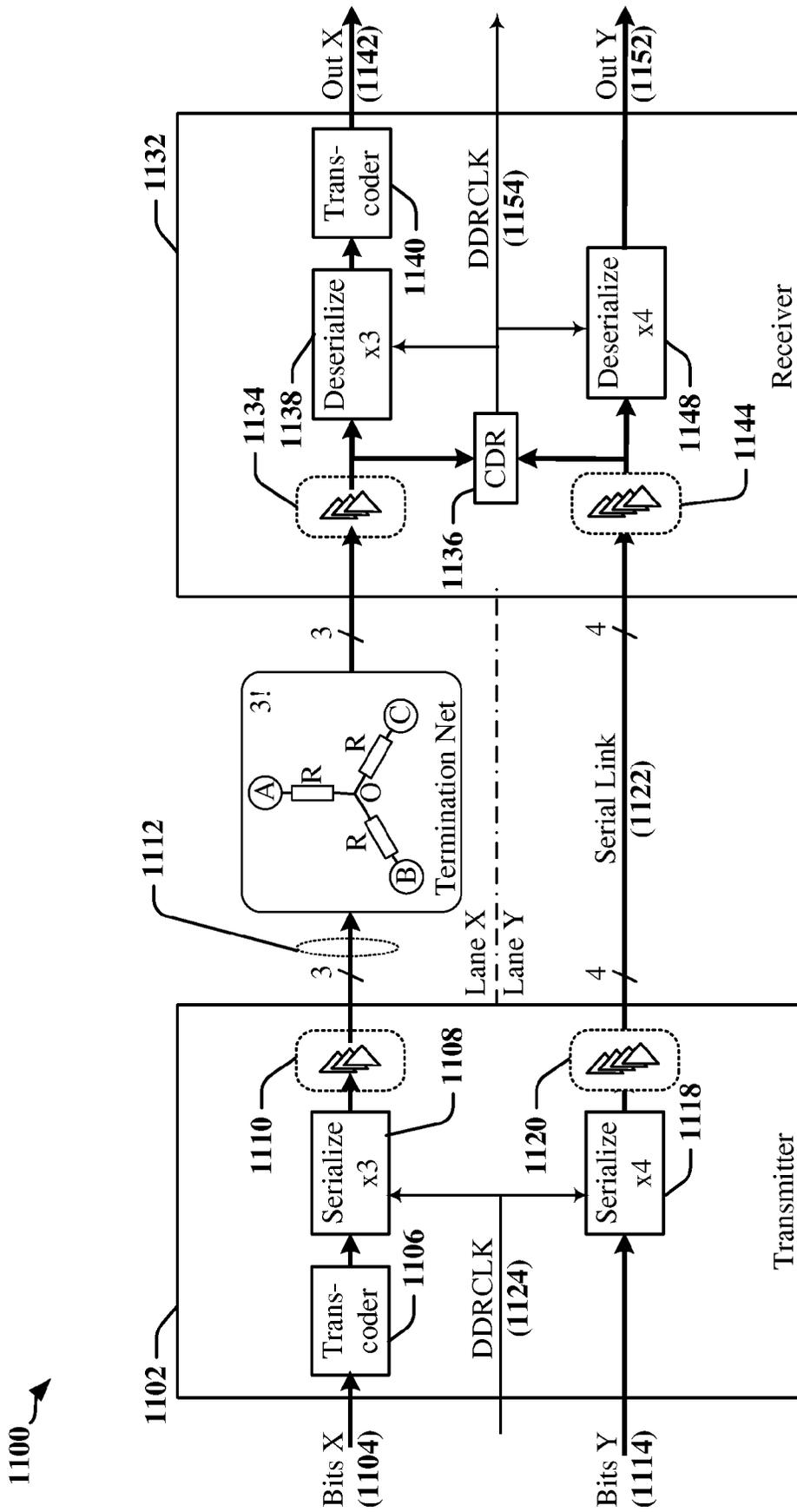
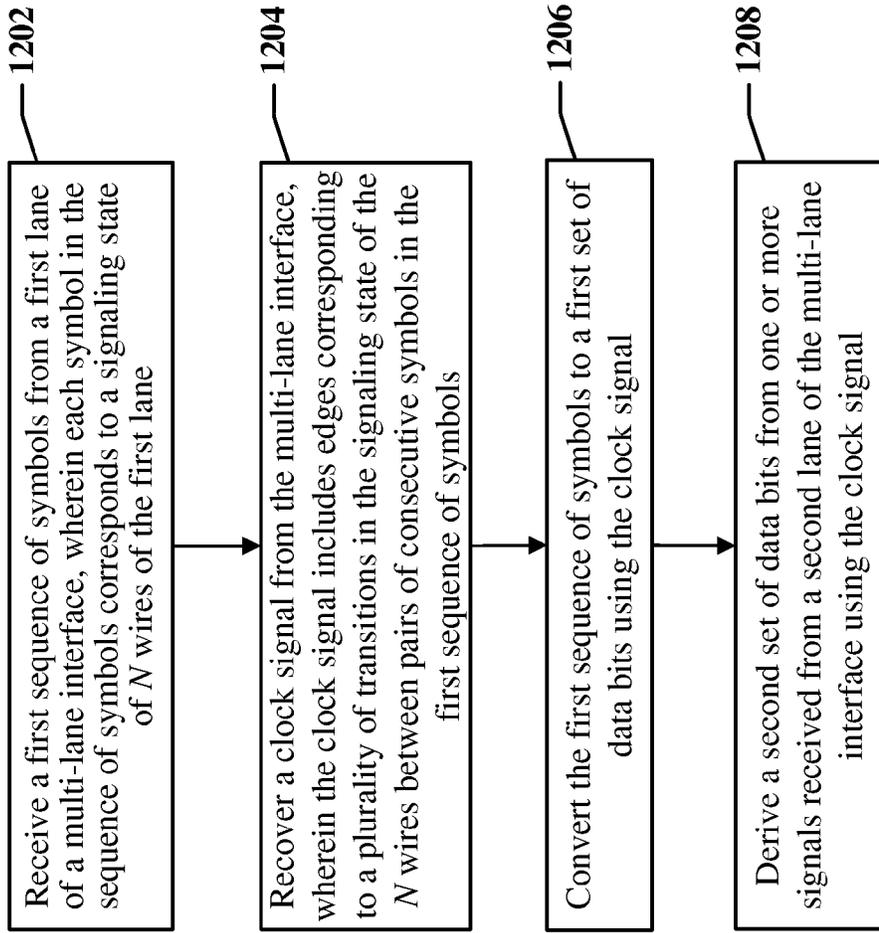


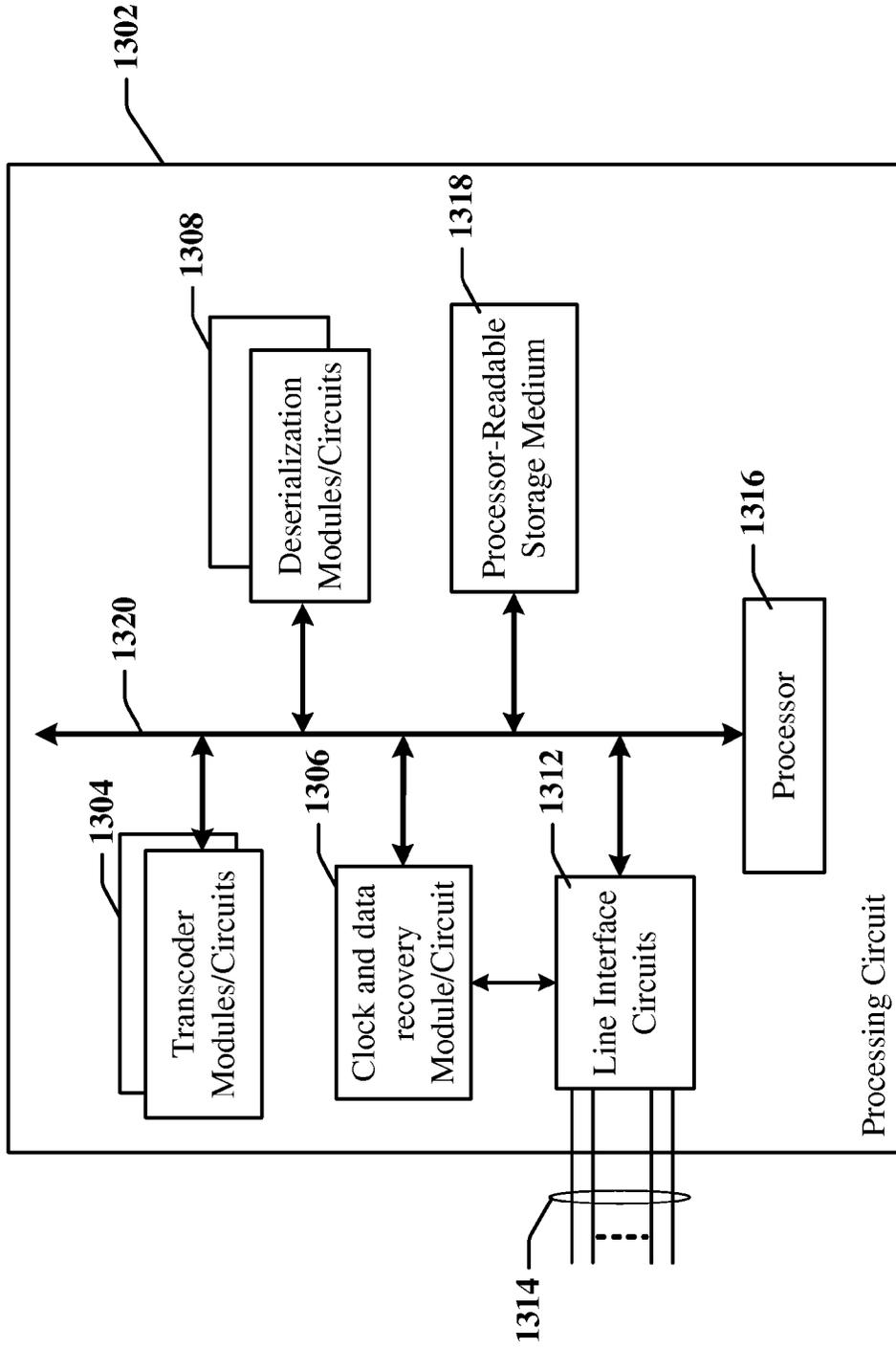
FIG. 11

1200 ↗



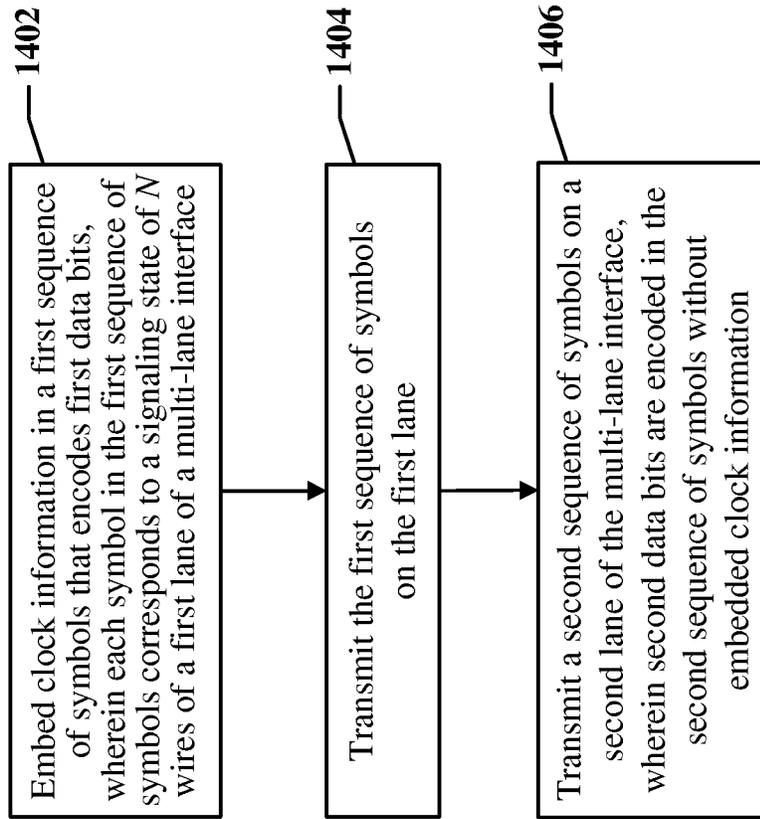
**FIG. 12**

1300 ↗



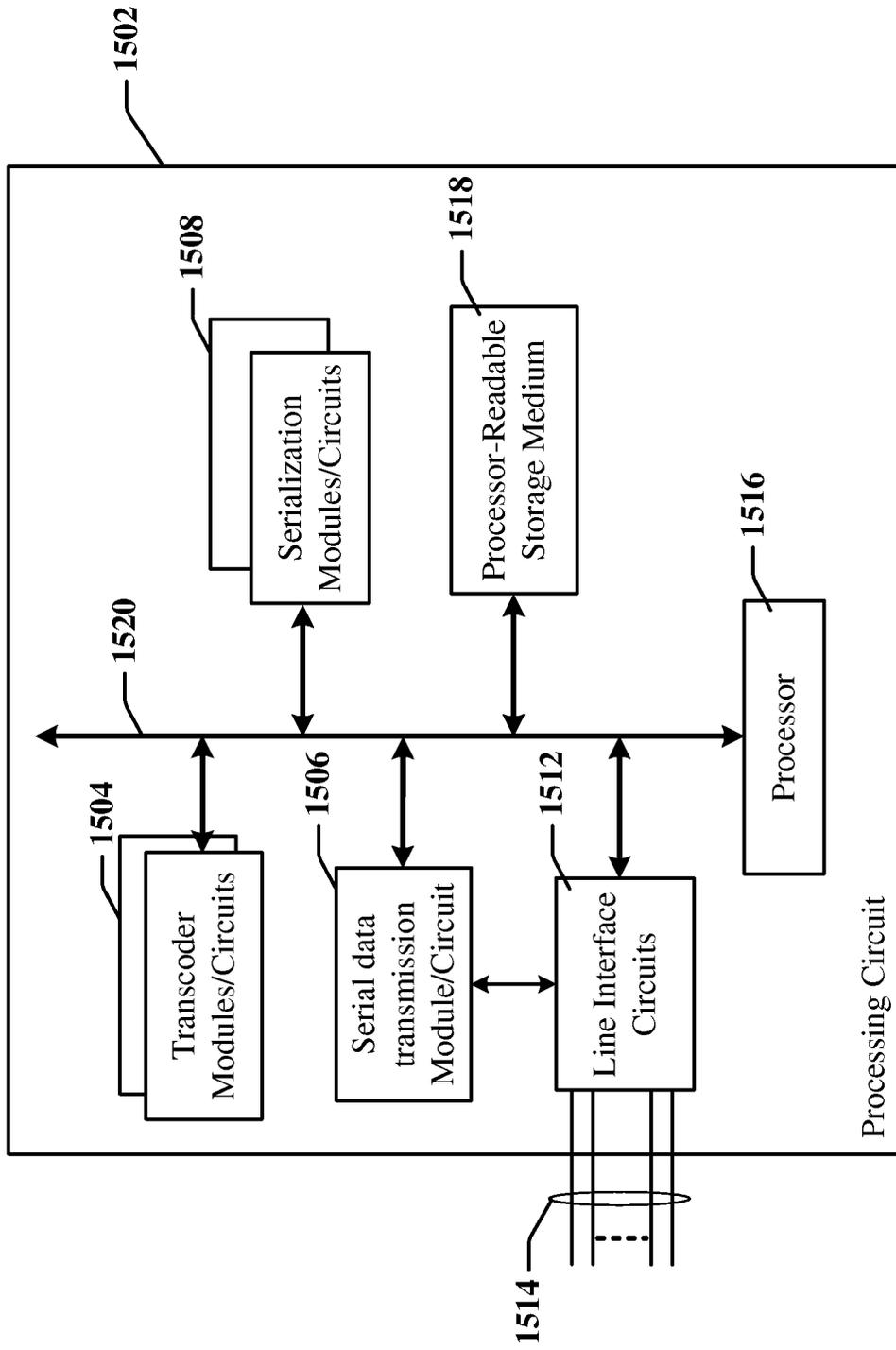
**FIG. 13**

1400 ↗



**FIG. 14**

1500 ↗



**FIG. 15**

# MULTI-LANE N-FACTORIAL (N!) AND OTHER MULTI-WIRE COMMUNICATION SYSTEMS

## BACKGROUND

### 1. Field

The present disclosure relates generally to data communications interfaces, and more particularly, multi-lane, multi-wire data communication interfaces.

### 2. Background

Manufacturers of mobile devices, such as cellular phones, may obtain components of the mobile devices from various sources, including different manufacturers. For example, an application processor in a cellular phone may be obtained from a first manufacturer, while the display for the cellular phone may be obtained from a second manufacturer. The application processor and a display or other device may be interconnected using a standards-based or proprietary physical interface. For example, a display may provide an interface that conforms to the Display System Interface (DSI) standard specified by the Mobile Industry Processor Interface Alliance (MIPI).

In one example, a multi-signal data transfer system may employ multi-wire differential signaling such as 3-phase or N-factorial (N!) low-voltage differential signaling (LVDS), transcoding (e.g., the digital-to-digital data conversion of one encoding type to another) may be performed to embed symbol clock information by causing a symbol transition at every symbol cycle, instead of sending clock information in separate data lanes (differential transmission paths). Embedding clock information by transcoding is an effective way to minimize skew between clock and data signals, as well as to eliminate the necessity of a phase-locked loop (PLL) to recover the clock information from the data signals.

There exists an ongoing need for optimized communications and improved data transfer rates on multi-signal communications links.

## SUMMARY

Embodiments disclosed herein provide systems, methods and apparatus related to multi-lane, multi-wire interfaces.

In an aspect of the disclosure, a method of data communications includes receiving a first sequence of symbols from a first lane of a multi-lane interface, recovering a clock signal from the multi-lane interface, converting the first sequence of symbols to a first set of data bits using the clock signal, and deriving a second set of data bits from one or more signals received from a second lane of the multi-lane interface using the clock signal. The clock signal may include edges corresponding to a plurality of transitions in the signaling state of the N wires between consecutive pairs of symbols in the first sequence of symbols. Each symbol in the sequence of symbols may correspond to a signaling state of N wires of the first lane.

In an aspect of the disclosure, converting the first sequence of symbols to the first set of data bits includes converting the first sequence of symbols to a set of transition numbers, and then converting the set of transition numbers to the first set of data bits. Converting the first sequence of symbols to the first set of data bits may include using a transcoder. The second set of data bits may be decoded without using a transcoder. In one example, the first sequence of symbols is received in  $N C_2$  differential signals transmitted on  $N C_2$  different pairs of the N wires. The second lane may include M wires.

In one example, a second sequence of symbols may be received in  $M C_2$  differential signals transmitted on  $M C_2$  different pairs of the M wires. The value of M may not be equal to the value of N. In some instances, M may be equal to N. In another example, deriving the second set of data bits includes receiving serial signals from each of M wires of a serial interface, and extracting the second set of data bits by sampling the serial signals in accordance with the clock signal. In some instances, deriving the second set of data bits may include receiving M/2 differential signals from M wires of a serial interface, and extracting the second set of data bits by sampling the M/2 differential signals in accordance with the clock signal.

In an aspect of the disclosure, the clock signal may include edges corresponding to one or more transitions in the signaling state of at least one wire of the second lane of the multi-lane interface. Recovering the clock signal may include providing a transition in the clock signal corresponding to a transition detected in the signaling state of the N wires of the first lane and/or in the signaling state of one or more wires of the second lane.

In an aspect of the disclosure, the first sequence of symbols is encoded in  $N C_2$  differential signals, whereby each of the  $N C_2$  differential signals is received from a different pair of the N wires, and a second sequence of symbols is encoded in  $M C_2$  differential signals received from M wires of the second lane, whereby each of the  $M C_2$  differential signals is received from a different pair of the M wires. A single transcoder may be used to convert the first sequence of symbols to the first set of data bits, and the second sequence of symbols to the second set of data bits.

In an aspect of the disclosure, a transition occurs in the signaling state of one or more of the N wires and/or of one or more of the M wires between each sequential pair of symbols in the first sequence of symbols.

In an aspect of the disclosure, an apparatus includes means for receiving a first sequence of symbols from a first lane of a multi-lane interface, means for recovering a clock signal from the first sequence of symbols based on transitions in the signaling state of the N wires of the first lane between consecutive pairs of symbols in the first sequence of symbols, means for converting the first sequence of symbols to a first set of data bits using the clock signal, and means for deriving a second set of data bits from one or more signals received from a second lane of the multi-lane interface using the clock signal. Each symbol in the sequence of symbols corresponds to a signaling state of the N wires.

In an aspect of the disclosure, a receiver includes a clock and data recovery (CDR) circuit configured to receive a first sequence of symbols from a first lane of a multi-lane interface, and recover a clock signal from the multi-lane interface by generating edges in the clock signal based on determinations of transitions in the signaling state of the plurality of wires of the first lane between consecutive pairs of symbols in the first sequence of symbols. Each symbol in the sequence of symbols may correspond to a signaling state of a plurality of wires of the first lane. The receiver includes first transcoding circuitry and first desequencing circuitry configured to convert the first sequence of symbols to a first set of data bits using the clock signal, and at least one of a second transcoding circuitry or a second desequencing circuitry configured to derive a second set of data bits from one or more signals received from a second lane of the multi-lane interface using the clock signal.

In an aspect of the disclosure, a processor-readable storage medium has one or more instructions stored or maintained thereon. When executed by at least one processing circuit, the

instructions may cause the at least one processing circuit to receive a first sequence of symbols from a first lane of a multi-lane interface, extract a clock signal from the first sequence of symbols based on transitions in the signaling state of N wires of the first lane between consecutive pairs of symbols in the first sequence of symbols, convert the first sequence of symbols to a first set of data bits using the clock signal, and derive a second set of data bits from one or more signals received from a second lane of the multi-lane interface using the clock signal. Each symbol in the sequence of symbols corresponds to a signaling state of the N wires.

In an aspect of the disclosure, a method of data communication includes embedding clock information with first data bits encoded in a first sequence of symbols, transmitting the first sequence of symbols on a first lane of a multi-lane interface, and transmitting a second sequence of symbols on a second lane of the multi-lane interface. Each symbol in the first sequence of symbols corresponds to a signaling state of N wires of the first lane. Second data bits may be encoded in a second sequence of symbols without embedded clock information.

In an aspect of the disclosure, the clock information relates to a transmit clock used to encode both the first sequence of symbols and the second sequence of symbols. The clock information may be embedded by using a transcoder to convert the first data bits to a set of transition numbers, and then convert the set of transition numbers to obtain the first sequence of symbols. The second data bits may be encoded in the second sequence of symbols without using a transcoder. The clock information may be embedded by causing a transition in the signaling state of the N wires of the first lane between each pair of consecutive symbols transmitted on the first lane or in the signaling state of M wires of the second lane between each consecutive pair of symbols in the second sequence of symbols. Data received during a first clock interval may be divided to obtain the first data bits and the second data bits. A first symbol corresponding to the first set of data bits may be transmitted on the first lane concurrently with a second symbol corresponding to the second set of data bits on the second lane.

In an aspect of the disclosure, the first sequence of symbols may be transmitted in  $N/2$  differential signals on  $N/2$  different pairs of the N wires. The second lane may include M wires. In one example, transmitting the second sequence of symbols may include transmitting the second sequence of symbols in  $M/2$  differential signals on  $M/2$  different pairs of the M wires. The values of M and N may be equal or unequal. In another example, second sequence of symbols is transmitted on M wires of a serial bus. In some instances, the second sequence of symbols is transmitted in  $M/2$  differential signals.

In an aspect of the disclosure, each symbol in the first sequence of symbols is transmitted in a different symbol interval. The clock information may be embedded by causing a transition in the signaling state of the N wires or in the signaling state of one or more wires of the second lane between each pair of consecutive symbols in the first sequence of symbols.

In an aspect of the disclosure, a single transcoder circuit is used to encode the first data bits in the first sequence of symbols and to encode the second data bits in the second sequence of symbols.

In an aspect of the disclosure, an apparatus includes means for embedding clock information with first data bits encoded in a first sequence of symbols, means for transmitting the first sequence of symbols on the first lane, and means for transmitting a second sequence of symbols on a second lane of the

multi-lane interface. Each symbol in the first sequence of symbols may correspond to a signaling state of N wires of a first lane of a multi-lane interface. Second data bits may be encoded in a second sequence of symbols without embedded clock information.

In an aspect of the disclosure, an apparatus includes a processing circuit configured to embed clock information with first data bits encoded in a first sequence of symbols, transmit the first sequence of symbols on the first lane, and transmit a second sequence of symbols on a second lane of the multi-lane interface. Each of the first sequence of symbols may correspond to a signaling state of N wires of a first lane of a multi-lane interface. Second data bits may be encoded in a second sequence of symbols without embedded clock information.

In an aspect of the disclosure, a processor-readable storage medium has one or more instructions stored or maintained thereon. When executed by at least one processing circuit, the instructions may cause the at least one processing circuit to embed clock information with first data bits encoded in a first sequence of symbols, transmit the first sequence of symbols on the first lane, and transmit a second sequence of symbols on a second lane of the multi-lane interface. Each of the first sequence of symbols may correspond to a signaling state of N wires of a first lane of a multi-lane interface. The second sequence of symbols is encoded with second data bits and without embedded clock information.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts an apparatus employing a data link between integrated circuit (IC) devices that selectively operates according to one of plurality of available standards.

FIG. 2 illustrates a system architecture for an apparatus employing a data link between IC devices.

FIG. 3 illustrates a CDR circuit that may be used in an N! communication interface.

FIG. 4 illustrates timing of certain signals generated by the CDR circuit of FIG. 3 in accordance with one or more aspects disclosed herein.

FIG. 5 illustrates an example of a basic N! multi-lane interface.

FIG. 6 illustrates a first example of a multi-lane interface provided according to one or more aspects disclosed herein.

FIG. 7 illustrates a second example of a multi-lane interface provided according to one or more aspects disclosed herein.

FIG. 8 illustrates a third example of a multi-lane interface provided according to one or more aspects disclosed herein.

FIG. 9 illustrates a fourth example of a multi-lane interface provided according to one or more aspects disclosed herein.

FIG. 10 is a timing diagram illustrating the ordering of data transmitted on a multi-lane interface provided according to one or more aspects disclosed herein.

FIG. 11 illustrates a fifth example of a multi-lane interface provided according to one or more aspects disclosed herein.

FIG. 12 is a flow chart of a method for operating a receiver in a multi-lane N-wire interface provided according to one or more aspects disclosed herein.

FIG. 13 is a diagram illustrating a simplified example of a receiver in a multi-lane N-wire interface provided according to one or more aspects disclosed herein.

FIG. 14 is a flow chart of a method for operating a transmitter in a multi-lane N-wire interface provided according to one or more aspects disclosed herein.

FIG. 15 is a diagram illustrating a simplified example of a transmitter in a multi-lane N-wire interface provided according to one or more aspects disclosed herein.

#### DETAILED DESCRIPTION

Various aspects are now described with reference to the drawings. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more aspects. It may be evident, however, that such aspect(s) may be practiced without these specific details.

As used in this application, the terms “component,” “module,” “system” and the like are intended to include a computer-related entity, such as, but not limited to hardware, firmware, a combination of hardware and software, software, or software in execution. For example, a component may be, but is not limited to being, a process running on a processor, a processor, an object, an executable, a thread of execution, a program and/or a computer. By way of illustration, both an application running on a computing device and the computing device can be a component. One or more components can reside within a process and/or thread of execution and a component may be localized on one computer and/or distributed between two or more computers. In addition, these components can execute from various computer readable media having various data structures stored thereon. The components may communicate by way of local and/or remote processes such as in accordance with a signal having one or more data packets, such as data from one component interacting with another component in a local system, distributed system, and/or across a network such as the Internet with other systems by way of the signal.

Moreover, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or.” That is, unless specified otherwise, or clear from the context, the phrase “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, the phrase “X employs A or B” is satisfied by any of the following instances: X employs A; X employs B; or X employs both A and B. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from the context to be directed to a singular form.

Certain aspects of the invention may be applicable to communications links deployed between electronic devices that may include subcomponents of an apparatus such as a telephone, a mobile computing device, an appliance, automobile electronics, avionics systems, etc. FIG. 1 depicts an apparatus that may employ a communication link between IC devices. In one example, the apparatus 100 may include a wireless communication device that communicates through a radio frequency (RF) transceiver with a radio access network (RAN), a core access network, the Internet and/or another network. The apparatus 100 may include a communications transceiver 106 operably coupled to processing circuit 102. The processing circuit 102 may comprise one or more IC devices, such as an application-specific IC (ASIC) 108. The ASIC 108 may include one or more processing devices, logic circuits, and so on. The processing circuit 102 may include and/or be coupled to processor readable storage such as a memory 112 that may maintain instructions and data that may be executed by processing circuit 102. The processing circuit 102 may be controlled by one or more of an operating system and an application programming interface (API) 110 layer that supports and enables execution of software modules residing in storage media, such as the memory device 112 of

the wireless device. The memory device 112 may include read-only memory (ROM) or random-access memory (RAM), electrically erasable programmable ROM (EEPROM), flash cards, or any memory device that can be used in processing systems and computing platforms. The processing circuit 102 may include or access a local database 114 that can maintain operational parameters and other information used to configure and operate the apparatus 100. The local database 114 may be implemented using one or more of a database module, flash memory, magnetic media, EEPROM, optical media, tape, soft or hard disk, or the like. The processing circuit may also be operably coupled to external devices such as an antenna 122, a display 124, operator controls, such as button 128 and keypad 126 among other components.

FIG. 2 is a block schematic illustrating certain aspects of an apparatus 200 connected to a communications bus, where the apparatus 200 may be embodied in one or more of a wireless mobile device, a mobile telephone, a mobile computing system, a wireless telephone, a notebook computer, a tablet computing device, a media player, a gaming device, or the like. The apparatus 200 may comprise a plurality of IC devices 202 and 230 that exchange data and control information through a communication link 220. The communication link 220 may be used to connect IC devices 202 and 230 that are located in close proximity to one another, or physically located in different parts of the apparatus 200. In one example, the communication link 220 may be provided on a chip carrier, substrate or circuit board that carries the IC devices 202 and 230. In another example, a first IC device 202 may be located in a keypad section of a flip-phone while a second IC device 230 may be located in a display section of the flip-phone. In another example, a portion of the communication link 220 may comprise a cable or optical connection.

The communication link 220 may include multiple channels 222, 224 and 226. One or more channels 226 may be bidirectional, and may operate in half-duplex and/or full-duplex modes. One or more channels 222 and 224 may be unidirectional. The communication link 220 may be asymmetrical, providing higher bandwidth in one direction. In one example described herein, a first communications channel 222 may be referred to as a forward link 222 while a second communications channel 224 may be referred to as a reverse link 224. The first IC device 202 may be designated as a host system or transmitter, while the second IC device 230 may be designated as a client system or receiver, even if both IC devices 202 and 230 are configured to transmit and receive on the communications link 222. In one example, the forward link 222 may operate at a higher data rate when communicating data from a first IC device 202 to a second IC device 230, while the reverse link 224 may operate at a lower data rate when communicating data from the second IC device 230 to the first IC device 202.

The IC devices 202 and 230 may each have a processor or other processing and/or computing circuit or device 206, 236. In one example, the first IC device 202 may perform core functions of the apparatus 200, including maintaining wireless communications through a wireless transceiver 204 and an antenna 214, while the second IC device 230 may support a user interface that manages or operates a display controller 232. The first IC device 202 or second IC device 230 may control operations of a camera or video input device using a camera controller 234. Other features supported by one or more of the IC devices 202 and 230 may include a keyboard, a voice-recognition component, and other input or output devices. The display controller 232 may include circuits and software drivers that support displays such as a liquid crystal display (LCD) panel, touch-screen display, indicators and so

on. The storage media **208** and **238** may include transitory and/or non-transitory storage devices adapted to maintain instructions and data used by respective processors **206** and **236**, and/or other components of the IC devices **202** and **230**. Communication between each processor **206**, **236** and its corresponding storage media **208** and **238** and other modules and circuits may be facilitated by one or more bus **212** and **242**, respectively.

The reverse link **224** may be operated in the same manner as the forward link **222**, and the forward link **222** and reverse link **224** may be capable of transmitting at comparable speeds or at different speeds, where speed may be expressed as data transfer rate and/or clocking rates. The forward and reverse data rates may be substantially the same or differ by orders of magnitude, depending on the application. In some applications, a single bidirectional link **226** may support communications between the first IC device **202** and the second IC device **230**. The forward link **222** and/or reverse link **224** may be configurable to operate in a bidirectional mode when, for example, the forward and reverse links **222** and **224** share the same physical connections and operate in a half-duplex manner. In one example, the communication link **220** may be operated to communicate control, command and other information between the first IC device **202** and the second IC device **230** in accordance with an industry or other standard.

In one example, forward and reverse links **222** and **224** may be configured or adapted to support a wide video graphics array (WVGA) 80 frames per second LCD driver IC without a frame buffer, delivering pixel data at 810 Mbps for display refresh. In another example, forward and reverse links **222** and **224** may be configured or adapted to enable communications between with dynamic random access memory (DRAM), such as double data rate synchronous dynamic random access memory (SDRAM). Encoding devices **210** and/or **230** can encode multiple bits per clock transition, and multiple sets of wires can be used to transmit and receive data from the SDRAM, control signals, address signals, and so on.

The forward and reverse links **222** and **224** may comply or be compatible with application-specific industry standards. In one example, the MIPI standard defines physical layer interfaces between an application processor IC device **202** and an IC device **230** that supports the camera or display in a mobile device. The MIPI standard includes specifications that govern the operational characteristics of products that comply with MIPI specifications for mobile devices. The MIPI standard may define interfaces that employ complimentary metal-oxide-semiconductor (CMOS) parallel busses.

In one example, the communication link **220** of FIG. 2 may be implemented as a wired bus that includes a plurality of signal wires (denoted as N wires). The N wires may be configured to carry data encoded in symbols, where clock information is embedded in a sequence of the symbols transmitted over the plurality of wires.

FIG. 3 illustrates an example of a clock and data recovery (CDR) circuit **300** that may be employed to recover embedded clock information in an N-wire system. FIG. 4 is a timing diagram **400** illustrating certain signals generated through the operation of the CDR circuit **300**. The CDR circuit **300** and its timing diagram **400** are provided by way of generalized example, although other variants of the CDR circuit **300** and/or other CDR circuits may be used in some instances. Signals received from N-wires **308** are initially processed by a number ( ${}_N C_2$ ) of receivers **302**, which produce a corresponding number of raw signals as outputs. In the illustrated example, N=4 wires **308** are processed by  ${}_4 C_2=6$  receivers **302** that produce a first state transition signal (SI signal) **320** that includes 6 raw signals representative of the received

symbol. For each raw signal output from each different receiver there may be a setup time **408** provided between symbols  $S_0$  **402**,  $S_1$  **404** and  $S_2$  **406** during which the state of the corresponding signal is undefined, indeterminate, transient or otherwise unstable. Level latches **310**, a comparator **304**, set-reset latch **306**, a one-shot circuit **326**, an analog delay element **312** and (bused) level latches **310** may be configured to generate a level-latched signal (S signal) **322** representative of a delayed instance of the SI signal **320**, where the delay before the SI signal **320** is captured by the level latches **310** to provide an updated S signal **322** may be selected by configuring a delay element (Delay S) **312**.

In operation, the comparator **304** compares the SI signal **320** with the S signal **322** and outputs a binary comparison signal (NE signal) **314**. The set-reset latch **306** may receive the NE signal **314** from the comparator **304** and output a signal (NEFLT signal) **316**, which is a filtered version of the NE signal **314**. The operation of the set-reset latch **306** can be configured to remove any transient instability in the NE signal **314**, where the transient instability is exhibited as spikes **410** in the NE signal **314**. The NEFLT signal **316** can be used to control the output latches **330** that capture the S signal **322** as data output **328**.

The one-shot circuit **326** receives the NEFLT signal **316** and produces a fixed width pulse **412**, which may then be delayed by the delay element **312** to produce a clock signal (SDRCLK) **318**. In some instances, the SDRCLK signal **318** may be used by external circuitry to sample the data output **328** of the CDR **300**. In one example, the SDRCLK signal **318** may be provided to decoder or deserializer circuits. The level latches **310** receive the SI signal **320** and output the S signal **322**, where the level latches **310** are triggered or otherwise controlled by the SDRCLK signal **318**.

In operation, the comparator **304** compares the SI signal **320** with the S signal **322**, which is output from the level latches **310**. The comparator **304** drives the NE signal **314** to a first state (e.g. logic low) when the SI signal **320** and the S signal **322** are equal, and to a second state (e.g. logic high) when the SI signal **320** and the S signal **322** are not equal. The NE signal **314** is in the second state when the SI signal **320** and the S signal **322** are representative of different symbols. Thus, the second state indicates that a transition is occurring.

As can be appreciated from the timing diagram **400**, the S signal **322** is essentially a delayed and filtered version of SI signal **320**, in which transients or glitches **408** have been removed because of the delay **414** between the SI signal **320** and the S signal **322**. Multiple transitions **408** in the SI signal **320** may be reflected as spikes **410** in the NE signal **314**, but these spikes **410** are masked from the NEFLT signal **316** through the operation of the set-reset circuit. Moreover, the SDRCLK **318** is resistant to line skew and glitches in the symbol transitions based on the use of the delays **326a**, **312** provided in the feedback path to the level-latch **310** and set-reset circuit **306**, whereby the SDRCLK signal **318** controls the reset function of the set-reset circuit **306**.

At the commencement **416** of a transition between a first symbol value  $S_0$  **402** and a next symbol value  $S_1$  **404**, the SI signal **320** begins to change state. The state of the SI signal **320** may be different from  $S_1$  **404** due to the possibility that intermediate or indeterminate states **408** during the transition between  $S_0$  **402** and  $S_1$  **404**. These intermediate or indeterminate states **408** may be caused, for example, by inter-wire skew, over/under shoot, cross-talk, etc.

The NE signal **314** becomes high as soon as the comparator **304** detects a difference in values between the SI signal **320** and the S signal **322**, and the transition high of the NE signal **314** asynchronously sets the set-reset latch **306** output, driv-

ing the NEFLT signal 316 high. The NEFLT signal 316 is maintained in its high state until the set-reset latch 306 is reset by a high state of the SDRCLK signal 318. The SDRCLK signal 318 is a delayed version of the NE1SHOT signal 324, which is a limited pulse-width version of the NEFLT signal 316. The SDRCLK signal 318 may be delayed with respect to the NE1SHOT signal 324 through the use of the analog delay circuit 312, for example.

The intermediate or indeterminate states 408 on SI 320 may represent invalid data. These intermediate or indeterminate states 408 may contain a short period of the previous symbol value  $S_0$  402, and may cause the NE signal 314 to return low for short periods of time. Transitions of the SI signal 320 may generate spikes 410 on the NE signal 314. The spikes 410 are effectively filtered out and do not appear in the NEFLT signal 316.

The high state of the NEFLT signal 316 causes the SDRCLK signal 318 to transition high after a delay period 340 caused by the delay circuit 312. The high state of SDRCLK signal 318 resets the set-reset latch 306 output, causing the NEFLT signal 316 to transition to a low state. The high state of the SDRCLK signal 318 also enables the level latches 310, and the SI signal 320 value may be output on the S signal 322.

The comparator 304 detects that the S signal 322 (for symbol  $S_1$  402) matches the symbol  $S_1$  402 value present on the SI signal 320 and switches its output (the NE signal 314) low. The low state of the NEFLT signal 316 causes the SDRCLK signal 318 to go low after a delay period 342 caused by the analog delay 312. This cycle repeats for each transition in the SI signal 320. At a time after the falling edge of the SDRCLK signal 318, a new symbol  $S_2$  406 may be received and may cause the SI signal 320 to switch its value in accordance with the next symbol  $S_2$  406.

FIG. 5 is a diagram illustrating one example of a multi-lane interface 500 provided between two devices 502 and 532. At a transmitter 502, transcoders 506, 516 may be used to encode data 504, 514 and clock information in symbols to be transmitted over a set of N wires on each lane 512, 522, using N-factorial (N!) encoding for example. The clock information is derived from respective transmit clocks 524, 526 and may be encoded in a sequence of symbols transmitted in  ${}_N C_2$  differential signals over the N wires by ensuring that a signaling state transition occurs on at least one of the  ${}_N C_2$  signals between consecutive symbols. When N! encoding is used to drive the N wires, each bit of a symbol is transmitted as a differential signal by one of a set of line drivers 510, 520, where the differential drivers in the set of line drivers 510, 520 are coupled to different pairs of the N wires. The number of available combinations of wire pairs and signals may be calculated to be  ${}_N C_2$ , and the number of available combinations determines the number of signals that can be transmitted over the N wires. The number of data bits 504, 514 that can be encoded in a symbol may be calculated based on the number of available signaling states available for each symbol transmission interval.

A termination impedance (typically resistive) couples each of the N wires to a common center point in a termination network 528, 530. It will be appreciated that the signaling states of the N wires reflects a combination of the currents in the termination network 528, 530 attributed to the differential drivers 510, 520 coupled to each wire. It will be further appreciated that the center point of the termination network 528, 530 is a null point, whereby the currents in the termination network 528, 530 cancel each other at the center point.

The N! encoding scheme need not use a separate clock channel and/or non-return-to-zero decoding because at least

one of the  ${}_N C_2$  signals in the link transitions between consecutive symbols. Effectively, each transcoder 506, 516 ensures that a transition occurs between each pair of symbols transmitted on the N wires by producing a sequence of symbols in which each symbol is different from its immediate predecessor symbol. In the example depicted in FIG. 5, each lane 512, 522 has N=4 wires and each set of 4 wires can carry  ${}_4 C_2=6$  differential signals. The transcoder 506, 516 may employ a mapping scheme to generate raw symbols for transmission on the N wires available on a lane 512, 522. The transcoder 506, 516 and serializer 508, 518 cooperate to produce raw symbols for transmission based on the input data bits 504, 514. At the receiver 532, a transcoder 540, 550 may employ a mapping to determine a transition number that characterizes a difference between a pair of consecutive raw symbols, symbols in a lookup table, for example. The transcoders 506, 516, 540, 550 operate on the basis that every consecutive pair of raw symbols includes two different symbols.

The transcoder 506, 516 at the transmitter 502 may select between the N!-1 states that are available at every symbol transition. In one example, a 4! system provides 4!-1=23 signaling states for the next symbol to be transmitted at each symbol transition. The bit rate may be calculated as  $\log_2(\text{available\_states})$  per cycle of the transmit clock 524, 526. In a system using double data rate (DDR) clocking, symbol transitions occur at both the rising edge and falling edge of the transmit clock 524, 526. In one example, two or more symbols can be transmitted per word (i.e. per transmit clock cycle), such that the total available states in the transmit clock cycle is  $({}_N C_2 - 1)^2 = (23)^2 = 529$  and the number of data bits 504, 514 that can transmitted per symbol may be calculated as  $\log_2(529) = 9.047$  bits.

A receiving device 532 receives the sequence of symbols using a set of line receivers 534, 544, where each receiver in the set of line receivers 534, 544 determines differences in signaling states on one pair of the N wires. Accordingly,  ${}_N C_2$  receivers are used in each lane 512, 522, where N represents the number of wires in the corresponding lane 512, 522. The  ${}_N C_2$  receivers 534, 544 produce a corresponding number of raw symbols as outputs.

In the depicted example, each lane 512, 522 has N=4 wires and the signals received on the four wires of each lane 512, 522 are processed by a corresponding set of line receivers 534 or 544 that includes 6 receivers ( ${}_4 C_2=6$ ) to produce a state transition signal that is provided to a corresponding CDR 536, 546 and deserializer 538, 548. The CDRs 536 and 546 may operate in generally the same manner as the CDR 300 of FIG. 3 and each CDR 536 and 546 may produce a receive clock signal 554, 556 that can be used by a corresponding deserializer 538, 548. The clock signal 554 may include a DDR clock signal that can be used by external circuitry to receive data provided by the transcoders 540, 550. Each transcoder 540, 550 decodes a block of received symbols from the corresponding deserializer 538, 548 by comparing each next symbol to its immediate predecessor. The transcoders 540, 550 produce output data 542 and 552 that corresponds to the data 504, 514 provided to the transmitter 502.

As illustrated in the example of FIG. 5, each lane 512, 522 may be operated independently, although in a typical application the data 504 transmitted over one lane 512 may be synchronized with the data 514 transmitted over another lane 522. In one example, data bits 504 for transmission over a first lane (in this example, Lane X) 512 are received by a first transcoder 506 which generates a set of raw symbols that, when transmitted in a predetermined sequence, ensure that a transition of signaling state occurs in at least one signal trans-

mitted on the 4 wires of the first lane **512**. A serializer **508** produces a sequence of symbol values provided to line drivers **510** that determine the signaling state of the 4 wires of the first lane **512** for each symbol interval. Concurrently, data bits **514** are received by a second transcoder **516** of a second lane (in this example, Lane Y) **522**. The second transcoder **516** generates a set of transition numbers that are serialized by a serializer **518** that converts the set of transition numbers to a sequence of symbol values provided to line drivers **520** that determine the signaling state of the 4 wires of the second lane **522** for each symbol interval. The sequence of the raw symbols ensure that a transition of signaling state occurs in at least one signal transmitted on the 4 wires of the second lane **522** between each pair of consecutive symbols.

FIG. 6 illustrates a first example of a multi-lane interface **600** provided according to certain aspects disclosed herein. The multi-lane interface **600** offers improved data throughput and reduced circuit complexity when clock information encoded in symbols transmitted on a first lane (here Lane X) **612** is used to receive symbols transmitted without encoded clock information on one or more other lanes, including Lane Y **622**. In the example depicted, each lane **612**, **622** includes 4 wires.

Data for transmission may be divided into two portions **604** and **614**, where each portion is transmitted on a different lane **612**, **622**. On a first lane **612**, data **604** and information related to the transmit clock **624** may be encoded using the transcoder/serializer **608** to obtain raw symbols that are serialized as described in relation to FIG. 5. At the receiver **632**, the output of receivers **634** associated with the first lane **612** is provided to a CDR **636**. The CDR **636** may be configured to detect transitions in signaling state in order to generate a receive clock **654** used by both deserializing and transcoding circuits **638** and **648** for both lanes **612**, **622**. First deserializing and transcoding circuits **638** extract data **642** from the raw symbols received from the first lane **612**, while second deserializing and transcoding circuits **648** extract data **652** from the raw symbols received from the second lane **622**.

For the second lane **622**, transmission data **614** may be provided to transcoding and serializing circuits **618** and transmitted on the second lane **622** without encoded clock information. The transcoding circuitry used to produce raw symbols for the second lane **622** may be significantly less complex than the transcoding circuitry used to produce raw symbols with embedded clock information for transmission on the first lane **612**. For example, transcoding circuits for the second lane **622** may not need to perform certain arithmetic operations and logic functions to guarantee state transition at every symbol boundary.

In the example depicted in FIG. 6, a DDR clocked 4-wire first lane **612** provides  $(4!-1)^2=(23)^2=529$  signaling states and can encode  $\log_2 529=9.047$  bits of data per word received **604**, **614**, while DDR clocked 4-wire second lane **622** provides  $(4!)^2=(24)^2=576$  signaling states and can encode  $\log_2 576=9.170$  bits of data per word. In another example, an interface may have two 3-wire lanes where clock information is encoded in the first lane, but not in the second lane. In this latter example, 7 symbols may be transmitted per word and the 3-wire first lane provides  $(3!-1)^7=(5)^7=78125$  signaling states and can encode  $\log_2 78125=16.253$  bits of data per word, while the 3-wire second lane provides  $(3!)^7=6^7=279936$  signaling states and can encode  $\log_2 279936=18.095$  bits of data in each clock cycle. By encoding clock information in a single lane of a multi-lane  $N!$ , a higher overall throughput can be accomplished with less hardware.

FIG. 7 illustrates another example of a multi-lane interface **700** provided in accordance with one or more aspects dis-

closed herein. The multi-lane interface **700** offers improved flexibility of design in addition to optimized data throughput and reduced circuit complexity. Here clock information encoded in the symbols transmitted on one lane (here Lane X) **712** may be used to receive symbols transmitted on one or more other lanes **722** that have different numbers of wires.

In the depicted example, data for transmission may be divided into a plurality of portions **704** and **714**, where each portion is to be transmitted on a different lane **712**, **722**. On a first lane **712**, data **704** and a transmit clock **724** may be converted by transcoding and serializing circuits **708** to a sequence of raw symbols as described in relation to FIGS. 5 and 6. On a second lane **722**, the received data **714** may be provided to transcoding and serializing circuits **718** and then transmitted without embedded clock information.

At the receiver **732**, the output of receivers **734** associated with the first lane **712** is provided to a CDR **736**. The CDR **736** may be configured to detect a transition in signaling state of the 3 wires in the first lane **712**, and to generate a receive clock **754** used by both deserializing and transcoding circuits **738** and **748** for both lanes **712**, **722**. First deserializing and transcoding circuits **738** extract data **742** from the raw symbols received from the first lane **712**, while second deserializing and transcoding circuits **748** extract data **752** from the raw symbols received from the second lane **722**.

In the example, the first lane **712** includes 3 wires configured for  $3!$  operation, while the second lane **722** includes 4 wires configured for  $4!$  operation. The first lane **712** can provide  $(3!-1)^2=(5)^2=25$  signaling states for a 2 symbol per word system, whereby  $\log_2 25=4.644$  bits of data can be encoded per word. The 4-wire second lane **722** provides  $(4!)^2=(24)^2=576$  signaling states and can encode  $\log_2 576=9.170$  bits of data per word.

Significant efficiencies can be obtained when a single lane **712** encodes clock information and variable numbers of wires may be assigned to other lanes **722**. In an example where 10 interconnects (wires or connectors) are available between two devices, a conventional  $3!$  system may configure three 3-wire lanes, with clock information encoded on each lane. Each of the three lanes provides 5 signaling states per symbol for a total of 15 states per symbol. However, a system provided according to certain aspects described herein may use the 10 interconnects to provide two  $3!$  lanes and one  $4!$  lane, where the clock information is encoded in a first  $3!$  lane. This combination of lanes provides a total of  $5 \times 6 \times 24 = 720$  signaling states per symbol, based on a first  $3!$  lane providing 5 states plus clock information per symbol, a second  $3!$  lane providing 6 states per symbol and a  $4!$  lane providing 24 states per symbol.

FIG. 8 illustrates another example of a multi-lane interface **800** provided in accordance with one or more aspects disclosed herein. The multi-lane interface **800** offers various benefits including improved decoding reliability, which may permit higher transmission rates. The configuration and operation of the multi-lane interface **800** in this example is similar to that of the multi-lane interface **600** of FIG. 6, except that the CDR **836** is configured to generate a receive clock **854** from transitions detected on either the first lane **812** or the second lane **822**. Accordingly, the CDR **836** receives the outputs of the receivers **834** and **844**. Variations in the delay between the symbol boundary and an edge of the receive clock **854** may be reduced because the CDR **836** generates a clock from the first detected transition on either lane **812**, or **822**. This approach can reduce the effect of variable transition times on the wires and/or variable switching times of the line drivers **810**, **820** or receivers **834**, **844**.

In operation, data for transmission may be received in two or more portions **804** and **814**, where the portions **804**, **814** are for transmission on different lanes **812**, **822**. A combination of a transcoder and serializer circuits **808** may encode data bits **X 804** and embed information related to a transmit clock **824** in a sequence of symbols to be transmitted on the first lane **812**, as described in relation to FIG. 5. At the receiver **832**, the outputs of both sets of receivers **834** and **844** are provided to the CDR **836**, which is configured to detect a transition in signaling state on either lane **812**, **822** and generate a receive clock **854** based on the transition. The receive clock **854** is used by both deserializing/transcoding circuits **838** and **848**, which produce respective first and second lane data outputs **842** and **852**.

FIG. 9 illustrates another example of a multi-lane interface **900** provided according to one or more aspects disclosed herein. In this example, the multi-lane interface **900** offers improved data throughput and encoding efficiency by ensuring that a transition in signaling state between consecutive symbol intervals occurs on any one of a plurality of lanes **912**, **922**. Accordingly, the percentage overhead associated with encoding the clock information can be reduced relative to a system in which the clock information is embedded in sequences of symbols transmitted on a single lane. In the multi-lane interface **900**, a first lane (here Lane X) **912** includes three wires that carry 3! encoded signals, while the second lane (here Lane Y) **922** includes four wires and is configured for 4! encoding. Different numbers and configurations of lanes may be employed, and the particular example depicted in FIG. 9 is provided for illustrative purposes only. A transcoder **906** may be adapted to combine data **904** and clock information in symbols to be transmitted over two or more lanes **912** and/or **922**.

Encoding efficiencies may be achieved by embedding clock information based on the combination of available signaling states for all lanes **912**, **922**. The clock information is embedded by ensuring that a transition in signaling state occurs on at least one lane **912**, **922** between consecutive symbol intervals. In operation, the transcoder **906** may be configured to produce different sets of symbols for each lane **912**, **922**. In one example, the data **904** received by a transmitter **902** according to a clock signal **924** may be transmitted as a first sequence of symbols encoded in three signals transmitted on the 3! first lane **912**, and a second sequence of symbols encoded in six signals concurrently transmitted on the 4! second lane **922**. The transcoder **906** embeds clock information by ensuring that a signaling state transition occurs on at least one of the lanes **912** and **922** between consecutive symbols. The total number of states per symbol interval is the product of the number of states per symbol transmitted on the first lane **912** and the number of states per symbol transmitted on the second lane **922**. Accordingly, the number of states available to the transcoder at each symbol interval, when clock information is embedded across both lanes **912**, **922** may be calculated as:

$$(N_{lane1}! \times N_{lane2}!) - 1 = (3! \times 4!) - 1 = (6 \times 24) - 1 = 143$$

In another example, the number of states available to the transcoder at each symbol interval, when clock information is embedded across two lanes that are encoded in three signals using 3! may be calculated as:

$$(N_{lane1}! \times N_{lane1}!) - 1 = (3! \times 3!) - 1 = (6 \times 6) - 1 = 35$$

The number of states available to the transcoder at each symbol transition governs the number of bits that can be transmitted in each receive data cycle.

TABLE 1

Bits sent in 7 symbols	Description
$\log_2(3! - 1)^7 = 16.2535$	One lane 3!
$\log_2(4! - 1)^7 = 31.6650$	One lane 4!
$\log_2((3! - 1) \times 4!)^7 = 48.3482$	3! and 4!, transcoding on 3!
$\log_2(3! \times (4! - 1))^7 = 49.7597$	3! and 4!, transcoding on 4!
$\log_2((3! \times 4!) - 1)^7 = 50.1191$	Transcoding on combined 3! and 4!

Table 1 and Table 2 illustrate increased coding efficiencies when clock information is embedded by a transcoder across two or more N! lanes. Table 1 relates to the multi-lane interface **900** of FIG. 9. As can be seen from the table, a maximum encoding efficiency is obtained when a transcoder **906** embeds the clock information by considering the sequences of symbols transmitted on both lanes **912**, **922**.

TABLE 2

Bits sent in 7 symbols	Description
$\log_2(3! - 1)^7 \times 2 = 32.5070$	Transcoding on each 3! lanes
$\log_2((3! - 1) \times 3!)^7 = 34.3482$	Transcoding on one 3! lane
$\log_2(3! \times 3! - 1)^7 = 36.1895$	Transcoding on combined 3! lanes

Table 2 relates to an example of a multi-lane interface that has two 3! lanes.

In the example of FIG. 9, the receiver **932** includes a CDR **936** that generates a receive clock **954** by detecting transitions on both lanes **912**, **922**. The deserializers **938**, **948** provide symbols received from respective lanes **912**, **922** to a transcoder **940** that reverses the transcoding performed by the transcoder **906** in the transmitter. The transcoder **940** in the receiver **932** operates by examining the combined sequences of received symbols to produce output data **942**, which corresponds to the data **904** received at the transmitter **902**. Sets of line drivers **910**, **920** and receivers **934**, **944** may be provided according to the number of wires in the N! lanes **912**, **922**.

The multi-lane interface **900** can be configured to provide additional advantages over conventional interfaces. FIG. 10 illustrates an example in which a transcoder **1024** can be used to control the order of delivery of data to a receiver. One multi-lane interface **1000** such as the multi-lane interface **500** in FIG. 5 may independently encode two or more sets of data bits **1002**, **1004** in sequences of symbols **1006**, **1008** for transmission over a corresponding number of lanes. Data may be provided to the multi-lane interface **1000** pre-divided into the sets of data bits **1002**, **1004**, and/or the sets of data bits **1002**, **1004** may be split by the multi-lane interface **1000**. Data bits may be allocated among the two or more sets of data bits **1002**, **1004** arbitrarily, according to function, design preference or for convenience and/or other reasons.

In the illustrated multi-lane interface **1000**, each word, byte or other data element received in a first clock cycle may be encoded into two or more symbols transmitted sequentially in a pair of symbol intervals **1012a-1012g** on one of the two lanes. The receiver can decode the data element when the two or more symbols are received from the pair of symbol intervals **1012a-1012g**.

A multi-lane interface **1020**, such as the multi-lane interface **900** of FIG. 9, may include a transcoder **1024** that encodes data **1022** and clock information into a plurality of sequences of symbols **1026**, **1028** concurrently transmitted over two or more lanes. The transcoder **1024** may control the order of delivery of data to a receiver by concurrently transmitting symbols for transmission on two lanes. In one

15

example, data bits **1022** received in a first clock cycle (Bits (0)) may be transcoded into two symbols and transmitted in parallel on two lanes during a first symbol interval **1030**. Data bits **1022** received in a second clock cycle (Bits(1)) may be transmitted as two symbols in parallel on the two lanes during a second symbol interval **1032**. Transmission of data on two parallel data lanes may provide certain benefits for timing-sensitive applications such as shutter and/or flash control in a camera, control signals associated with game applications.

FIG. **11** illustrates another example of a multi-lane interface **1100** provided in accordance with one or more aspects disclosed herein. In this example, the multi-lane interface **1100** includes at least one N! encoded lane **1112** and a serial data link **1122**. The serial data link **1122** may be a single ended serial link (as illustrated) or a differentially encoded serial data link. The serial data link **1122** may include a serial bus, such as an Inter-Integrated Circuit (I2C) bus, a camera control interface (CCI) serial bus or derivatives of these serial bus technologies. In the example depicted, a clock signal **1124** is used by the serializer **1108** of the N! link and the serializer **1118** of the serial link **1122**, and the clock signal **1124** need not be transmitted to the receiver **1132** over a separate clock signal lane. Instead, a transcoder **1106** embeds clock information in a sequence of symbols that is provided through the serializer to the differential line drivers of the N! lane **1112**.

At the receiver **1132**, a CDR **1136** generates a receiver clock signal **1154** from transitions detected at the outputs of receivers **1134**. The receiver clock signal **1154** is used by the N! link deserializer **1138** and the serial link deserializer **1148**. In some instances, the CDR **1136** may monitor the output of the line receivers **1144** associated with the serial link **1122** in order to improve detection of a transition between symbol intervals. The N! lane deserializer **1138** provides deserialized symbol information to the transcoder **1140**, which produces output data **1142** representative of the input data **1104** that is transmitted over the N! encoded lane **1112**.

In one example, a transmitter **1102** transmits symbols in three signals on a 3! encoded first lane **1112**. The symbols include embedded clock information and 5 signaling states per symbol are available on the first lane **1112**. The transmitter may also send data on a second lane using 4 serial signals transmitted on the wires of a serial link **1122**. The receiver **1132** may generate a clock signal **1154** from the symbols transmitted on the first lane **1112**, where the clock is used to decode/deserialize data transmitted on both lanes **1112**, **1122**. Accordingly, the serial link **1112** provides  $2^4=16$  states per symbol when the clock **1154** provided by the CDR **1136** is used by the deserializer **1148** for the second lane serial link **1122**. An aggregate of  $5 \times 16=80$  states per symbol is achieved when the clock **1154** provided by the CDR **1136** is used.

By way of comparison, a conventional or traditional four-wire serial link **1122** may dedicate one of the four wires for carrying a clock signal, and data transmission may be limited to three signals on the other three of the 4 wires. In this latter configuration,  $2^3=8$  signaling states per symbol may be provided on the serial link **1122**, and an aggregate of  $5 \times 8=40$  signaling states per symbol results when data is also transmitted in the 3! encoded first lane **1112**.

FIG. **12** is a flowchart **1200** illustrating a method for data communications on an N-wire communications link. The communications link may include a plurality of connectors that carry symbols encoded using a suitable encoding scheme, such as N! encoding, multiphase encoding, multi-wire differential encoding, etc. The connectors may include electrically conductive wires, optical signal conductors,

16

semi-conductive interconnects and so on. The method may be performed by one or more processors of a receiving device.

At step **1202**, a first sequence of symbols is received from a first lane of a multi-lane interface. Each symbol in the sequence of symbols may correspond to a signaling state of N wires of the first lane.

At step **1204**, a clock signal is recovered or extracted from the multi-lane interface. The clock signal may include edges corresponding to a plurality of transitions in the signaling state of the N wires between pairs of consecutive symbols in the first sequence of symbols.

At step **1206**, the first sequence of symbols is converted to a first set of data bits using the clock signal. The first sequence of symbols may be converted to the first set of data bits by using a transcoder to convert the first sequence of symbols to a set of transition numbers, and converting the set of transition numbers to obtain the first set of data bits.

At step **1208**, a second set of data bits is derived from one or more signals received from a second lane of the multi-lane interface using the clock signal. The second set of data bits may be derived without using a transcoder.

In accordance with certain aspects disclosed herein, the first sequence of symbols may be encoded in  $N C_2$  differential signals received from  $N C_2$  different pairs of the N wires. The second lane may include M wires, wherein a second sequence of symbols is encoded in  $M C_2$  differential signals received from  $M C_2$  different pairs of the M wires. M and N may have equal or have different values.

In accordance with certain aspects disclosed herein, deriving the second set of data bits includes receiving serial signals from each of M wires of a serial interface, and extracting the second set of data bits by sampling the serial signals in accordance with the clock signal. Deriving the second set of data bits may include receiving  $M/2$  differential signals from M wires of a serial interface, and extracting the second set of data bits by sampling the  $M/2$  differential signals in accordance with the clock signal.

In accordance with certain aspects disclosed herein, the clock signal may be recovered or extracted by providing a transition in the clock signal corresponding to a transition detected in the signaling state of the N wires or in the signaling state of one or more wires of the second lane. The clock signal may include edges corresponding to one or more transitions in the signaling state of at least one wire of the second lane of the multi-lane interface.

In accordance with certain aspects disclosed herein, the first sequence of symbols is encoded in  $N C_2$  differential signals. Each of the  $N C_2$  differential signals may be received from a different pair of the N wires. A second sequence of symbols may be encoded in  $M C_2$  differential signals received from M wires of the second lane. Each of the  $M C_2$  differential signals may be received from a different pair of the M wires. The first sequence of symbols may be converted to the first set of data bits using a transcoder circuit. The second sequence of symbols may be converted to the second set of data bits using the same transcoder circuit.

In accordance with certain aspects disclosed herein, a transition in the signaling state of one or more of the N wires and the M wires occurs between each sequential pair of symbols in the first sequence of symbols. Each of the first sequence of symbols may be transmitted in a different symbol interval. The first set of data bits and the second set of data bits received in each symbol interval may be combined to obtain a completed data element from the each symbol interval.

FIG. **13** is a diagram illustrating a simplified example of a hardware implementation for an apparatus **1300** employing a processing circuit **1302**. The processing circuit typically has

a processor **1316** that may include one or more of a micro-processor, microcontroller, digital signal processor, a sequencer and a state machine. The processing circuit **1302** may be implemented with a bus architecture, represented generally by the bus **1320**. The bus **1320** may include any number of interconnecting buses and bridges depending on the specific application of the processing circuit **1302** and the overall design constraints. The bus **1320** links together various circuits including one or more processors and/or hardware modules, represented by the processor **1316**, the modules or circuits **1304**, **1306** and **1308**, line interface circuits **1312** configurable to communicate over connectors or wires **1314** and the computer-readable storage medium **1318**. The bus **1320** may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further.

The processor **1316** is responsible for general processing, including the execution of software stored on the computer-readable storage medium **1318**. The software, when executed by the processor **1316**, causes the processing circuit **1302** to perform the various functions described supra for any particular apparatus. The computer-readable storage medium **1318** may also be used for storing data that is manipulated by the processor **1316** when executing software, including data decoded from symbols transmitted over the connectors **1314**. The processing circuit **1302** further includes at least one of the modules **1304**, **1306** and **1308**. The modules **1304**, **1306** and **1308** may be software modules running in the processor **1316**, resident/stored in the computer-readable storage medium **1318**, one or more hardware modules coupled to the processor **1316**, or some combination thereof. The modules **1304**, **1306** and/or **1308** may include microcontroller instructions, state machine configuration parameters, or some combination thereof.

In one configuration, the apparatus **1300** for wireless communication includes modules and/or circuits **1306**, **1312** configured to receive a first sequence of symbols from a first lane of a multi-lane interface **1314**, a module and/or circuit **1306** configured to recover a clock signal from the multi-lane interface **1314**, where the clock signal includes edges corresponding to a plurality of transitions in the signaling state of the N wires occurs between pairs of consecutive symbols in the first sequence of symbols, modules and/or circuits **1304** and/or **1308** configured to convert the first sequence of symbols to a first set of data bits using the clock signal, and modules and/or circuits **1304** and/or **1308** configured to derive a second set of data bits from one or more signals received from a second lane of the multi-lane interface **1314** using the clock signal. In one example, the circuits illustrated in FIGS. **6-9** and **11** provides logic which implement the various functions performed by the apparatus **1300**.

In an aspect of the disclosure, the processor-readable storage medium **1318** has one or more instructions stored or maintained thereon. When executed by at least one processor **1316** of the processing circuit **1302**, the instructions may cause the processing circuit **1302** to receive a first sequence of symbols from a first lane of a multi-lane interface **1314**, recover a clock signal from the multi-lane interface **1314**, wherein the clock signal includes edges corresponding to a plurality of transitions in the signaling state of the N wires between pairs of consecutive symbols in the first sequence of symbols, convert the first sequence of symbols to a first set of data bits using the clock signal, and derive a second set of data bits from one or more signals received from a second lane of

the multi-lane interface **1314** using the clock signal. Each symbol in the sequence of symbols may correspond to a signaling state of the N wires.

The aforementioned means may be implemented, for example, using some combination of a processor **206** or **236**, physical layer drivers **210** or **240** and storage media **208** and **238**.

FIG. **14** is a flowchart **1400** illustrating a method for data communications on an N-wire communications link. The communications link may include a plurality of connectors that carry symbols encoded using a suitable encoding scheme, such as N! encoding, multiphase encoding, multi-wire differential encoding, etc. The connectors may include electrically conductive wires, optical signal conductors, semi-conductive interconnects and so on. The method may be performed by one or more processors of a receiving device.

At step **1402**, clock information is embedded in a first sequence of symbols that encodes first data bits. Each of the first sequence of symbols may correspond to a signaling state of N wires of a first lane of a multi-lane interface. The clock information may be encoded by using a transcoder to convert the first data bits to a set of transition numbers, and convert the set of transition numbers to obtain the first sequence of symbols. The second data bits may be encoded in the second sequence of symbols without using a transcoder.

At step **1404**, the first sequence of symbols is transmitted on the first lane.

At step **1406**, a second sequence of symbols is transmitted on a second lane of the multi-lane interface. The second sequence of symbols may be encoded with second data bits and without embedded clock information.

In accordance with certain aspects disclosed herein, the first sequence of symbols may be transmitted by transmitting the first sequence of symbols in  ${}_N C_2$  differential signals on  ${}_N C_2$  different pairs of the N wires. The second lane may include M wires. The second sequence of symbols may be transmitted in  ${}_M C_2$  differential signals on  ${}_M C_2$  different pairs of the M wires. The values of M and N may be equal or different.

In accordance with certain aspects disclosed herein, the second sequence of symbols may be transmitted on M wires of a serial bus. Transmitting the second sequence of symbols may include transmitting the second set of data in M/2 differential signals.

In accordance with certain aspects disclosed herein, each of the first sequence of symbols is transmitted in a different symbol interval. Embedding the clock information may include causing a transition in the signaling state of the N wires or in the signaling state of one or more wires of the second lane between each pair of consecutive symbols in the first sequence of symbols.

In accordance with certain aspects disclosed herein, a single transcoder circuit may be used to encode the first data bits in the first sequence of symbols and to encode the second data bits in the second sequence of symbols.

In accordance with certain aspects disclosed herein, embedding the clock information includes causing a transition in the signaling state of the N wires between each pair of consecutive symbols in the first sequence of symbols or in the signaling state of M wires of the second lane between each pair of consecutive symbols in the second sequence of symbols. The clock information may relate to a transmit clock used to encode both the first sequence of symbols and the second sequence of symbols.

In accordance with certain aspects disclosed herein, a data element may be divided to obtain the first set of data bits and the second set of data bits. A first symbol corresponding to the

first set of data bits may be transmitted on the first lane concurrently with transmission of a second symbol corresponding to the second set of data bits on the second lane.

FIG. 15 is a diagram illustrating a simplified example of a hardware implementation for an apparatus 1500 employing a processing circuit 1502. The processing circuit typically has a processor 1516 that may include one or more of a micro-processor, microcontroller, digital signal processor, a sequencer and a state machine. The processing circuit 1502 may be implemented with a bus architecture, represented generally by the bus 1520. The bus 1520 may include any number of interconnecting buses and bridges depending on the specific application of the processing circuit 1502 and the overall design constraints. The bus 1520 links together various circuits including one or more processors and/or hardware modules, represented by the processor 1516, the modules or circuits 1504, 1506 and 1508, line interface circuits 1512 configurable to communicate over connectors or wires 1514 and the computer-readable storage medium 1518. The bus 1520 may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further.

The processor 1516 is responsible for general processing, including the execution of software stored on the computer-readable storage medium 1518. The software, when executed by the processor 1516, causes the processing circuit 1502 to perform the various functions described supra for any particular apparatus. The computer-readable storage medium 1518 may also be used for storing data that is manipulated by the processor 1516 when executing software, including data decoded from symbols transmitted over the connectors 1514. The processing circuit 1502 further includes at least one of the modules 1504, 1506 and 1508. The modules 1504, 1506 and 1508 may be software modules running in the processor 1516, resident/stored in the computer-readable storage medium 1518, one or more hardware modules coupled to the processor 1516, or some combination thereof. The modules 1504, 1506 and/or 1508 may include microcontroller instructions, state machine configuration parameters, or some combination thereof.

In one configuration, the apparatus 1500 for wireless communication includes a module and/or circuit 1504 configured to embed information with first data bits encoded in a first sequence of symbols, modules and/or circuits 1506, 1512 configured to transmit the first sequence of symbols on a first lane of a multi-lane interface the first lane, modules and/or circuits 1504, 1506 and/or 1508 configured to transmit a second sequence of symbols on a second lane of the multi-lane interface. In one example, the circuits illustrated in FIGS. 6-9 and 11 provides logic which implement the various functions performed by the apparatus 1500.

In an aspect of the disclosure, a processor-readable storage medium 1516 has one or more instructions stored or maintained thereon. When executed by at least one processor 1516 of the processing circuit 1502, the instructions may cause the processor 1516 to embed clock information with first data bits encoded in a first sequence of symbols, transmit the first sequence of symbols on a first lane of the multi-lane interface 1514, and transmit a second sequence of symbols on a second lane of the multi-lane interface 1514. Each of the first sequence of symbols may correspond to a signaling state of N wires of a first lane of a multi-lane interface 1514. The second sequence of symbols may be encoded with second data bits and without embedded clock information.

The aforementioned means may be implemented, for example, using some combination of a processor 206 or 236, physical layer drivers 210 or 240 and storage media 208 and 238.

It is understood that the specific order or hierarchy of steps in the processes disclosed is an illustration of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Unless specifically stated otherwise, the term "some" refers to one or more. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed as a means plus function unless the element is expressly recited using the phrase "means for."

What is claimed is:

1. A method of data communications, comprising:

receiving a first sequence of symbols from a first lane of a multi-lane interface, wherein each symbol in the sequence of symbols corresponds to a signaling state of N wires of the first lane;

recovering a clock signal from the multi-lane interface, wherein the clock signal includes edges corresponding to a plurality of transitions in the signaling state of the N wires between pairs of consecutive symbols in the first sequence of symbols;

converting the first sequence of symbols to a first set of data bits using the clock signal; and

deriving a second set of data bits from one or more signals received from a second lane of the multi-lane interface using the clock signal, wherein converting the first sequence of symbols to the first set of data bits comprises:

using a transcoder to convert the first sequence of symbols to a set of transition numbers; and

converting the set of transition numbers to the first set of data bits.

2. The method of claim 1, wherein the second set of data bits are decoded without using a transcoder.

3. The method of claim 1, wherein the first sequence of symbols is received in  $N C_2$  differential signals transmitted on  $N C_2$  different pairs of the N wires.

4. The method of claim 3, wherein the second lane comprises M wires and a second sequence of symbols is received from  $M C_2$  differential signals transmitted on  $M C_2$  different pairs of the M wires, and wherein M is not equal to N.

5. The method of claim 3, wherein the second lane comprises M wires and a second sequence of symbols is received

21

from  $M C_2$  differential signals transmitted on  $M C_2$  different pairs of the M wires, and wherein M is equal to N.

6. The method of claim 3, wherein deriving the second set of data bits includes:

receiving serial signals from each of M wires of a serial interface; and

extracting the second set of data bits by sampling the serial signals in accordance with the clock signal.

7. The method of claim 3, wherein deriving the second set of data bits includes:

receiving  $M/2$  differential signals from M wires of a serial interface; and

extracting the second set of data bits by sampling the  $M/2$  differential signals in accordance with the clock signal.

8. The method of claim 1, wherein the clock signal includes one or more edges corresponding to one or more transitions in the signaling state of at least one wire of the second lane of the multi-lane interface.

9. The method of claim 1, wherein recovering the clock signal includes:

providing a transition in the clock signal corresponding to a transition detected in the signaling state of the N wires or in the signaling state of one or more wires of the second lane.

10. The method of claim 1, wherein the first sequence of symbols is received from  $N C_2$  differential signals, each of the  $N C_2$  differential signals being received from a different pair of the N wires, and a second sequence of symbols is received from  $M C_2$  differential signals, each of the  $M C_2$  differential signals being received from a different pair of M wires of the second lane, and further comprising:

converting the first sequence of symbols to the first set of data bits using a transcoder circuit; and

converting the second sequence of symbols to the second set of data bits using the transcoder circuit.

11. The method of claim 10, wherein a transition in the signaling state of one or more of the N wires and the M wires occurs between each sequential pair of symbols in the first sequence of symbols.

12. A receiver, comprising:

a clock and data recovery (CDR) circuit configured to:

receive a first sequence of symbols from a first lane of a multi-lane interface, wherein each symbol in the sequence of symbols corresponds to a signaling state of a plurality of wires of the first lane; and

recover a clock signal from the multi-lane interface, wherein the clock signal includes edges corresponding to a plurality of transitions in the signaling state of the plurality of wires of the first lane between pairs of consecutive symbols in the first sequence of symbols;

first transcoding circuitry and first deserializing circuitry configured to convert the first sequence of symbols to a first set of data bits using the clock signal, wherein the first transcoding and the first deserializing circuitry are configured to:

convert the first sequence of symbols to a set of transition numbers; and

converting the set of transition numbers to obtain the first set of data bits; and

at least one of a second transcoding circuitry or a second deserializing circuitry configured to derive a second set of data bits from one or more signals received from a second lane of the multi-lane interface using the clock signal.

13. The receiver of claim 12, wherein the CDR circuit is configured to recover the clock signal by generating an edge

22

in the clock signal based on a determination of a transition in the signaling state of at least one wire of the second lane of the multi-lane interface.

14. The receiver of claim 12, wherein the second set of data bits is decoded without using a transcoder.

15. A method of data communications, comprising:

embedding clock information in a first sequence of symbols that encodes first data bits, wherein each symbol in the first sequence of symbols corresponds to a signaling state of N wires of a first lane of a multi-lane interface; transmitting the first sequence of symbols on the first lane; and

transmitting a second sequence of symbols on a second lane of the multi-lane interface, wherein second data bits are encoded in the second sequence of symbols without embedded clock information, wherein embedding the clock information includes:

using a transcoder to convert the first data bits to a set of transition numbers; and

converting the set of transition numbers to obtain the first sequence of symbols.

16. The method of claim 15, wherein the second data bits are encoded in the second sequence of symbols without using a transcoder.

17. The method of claim 15, wherein transmitting the first sequence of symbols includes:

transmitting the first sequence of symbols in  $N C_2$  differential signals on  $N C_2$  different pairs of the N wires.

18. The method of claim 17, wherein the second lane comprises M wires, and wherein transmitting the second sequence of symbols includes:

transmitting the second sequence of symbols in  $M C_2$  differential signals on  $M C_2$  different pairs of the M wires, wherein M is not equal to N.

19. The method of claim 18, wherein the second sequence of symbols is transmitted on M wires of a serial bus.

20. The method of claim 19, wherein transmitting the second sequence of symbols includes:

transmitting the second set of data in  $M/2$  differential signals.

21. The method of claim 15, wherein the clock information relates to a transmit clock used to encode both the first sequence of symbols and the second sequence of symbols.

22. The method of claim 15, wherein embedding the clock information includes:

causing a transition in the signaling state of the N wires of the first lane or in the signaling state of one or more wires of the second lane between each pair of consecutive symbols transmitted on the first lane.

23. The method of claim 15, further comprising:

using a single transcoder circuit to encode the first data bits in the first sequence of symbols and to encode the second data bits in the second sequence of symbols.

24. The method of claim 23, wherein the second lane comprises M wires, and wherein embedding the clock information includes:

causing a transition in the signaling state of the N wires or in the signaling state of the M wires between transmissions of a pair of consecutive symbols in the first sequence of symbols.

25. The method of claim 23, further comprising:

dividing data received during a first clock interval to obtain the first data bits and the second data bits; and

transmitting a first symbol corresponding to the first data bits on the first lane concurrently with a second symbol corresponding to the second data bits on the second lane.

26. An apparatus comprising:  
 means for embedding clock information in a first sequence  
 of symbols that encodes first data bits, wherein each  
 symbol in the first sequence of symbols corresponds to a  
 signaling state of N wires of a first lane of a multi-lane 5  
 interface;  
 means for transmitting the first sequence of symbols on the  
 first lane; and  
 means for transmitting a second sequence of symbols on a  
 second lane of the multi-lane interface, wherein second 10  
 data bits are encoded in the second sequence of symbols  
 without embedded clock information,  
 wherein the means for embedding clock information in the  
 first sequence of symbols includes a transcoder config-  
 ured to: 15  
 convert the first data bits to a set of transition numbers,  
 wherein the set of transition numbers is used to select  
 the first sequence of symbols.

27. The apparatus of claim 26, wherein the clock informa-  
 tion relates to a transmit clock used to encode both the first 20  
 sequence of symbols and the second sequence of symbols.

28. The apparatus of claim 26, wherein each symbol in the  
 first sequence of symbols is transmitted in a different symbol  
 interval, and wherein the means for embedding clock informa-  
 tion is configured to cause a transition in the signaling state 25  
 of the N wires or in the signaling state of one or more wires of  
 the second lane between each pair of consecutive symbols in  
 the first sequence of symbols.

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